Volume 53 December 1958 Number 8

Economic Geology

and the

Bulletin of the Society of Economic Geologists

CONTENTS

Isotopic Study of Some Colorado Plateau Ores ... *Donald S. Miller and J. Laurence Kulp* 937

Structural Relations at the Hideout No. 1 Uranium Mine, Deer Flat Area, San Juan County, Utah ... *Tommy L. Finnell and William B. Gazdik* 949

The Influence of Ionic Substitution On the Stability of Micas and Chlorites ... *R. C. DeVries and Rustum Roy* 958

Banded Pyrite Deposits of Minas Carlota, Cuba ... *Patrick Arthur Hill* 966

Structure of the Ore Deposits at Santa Barbara, Chihuahua, Mexico ... *J. B. Scott* 1004

Discussions:

Supergene Copper Uranium Deposits, Nova Scotia ... *John F. McCauley* 1038

The Classification of Metalliferous Provinces and Deposits ... *Thomas M. Broderick* 1042

Mineralogy of Phosphate Oolites ... *G. W. Martin* 1046

Uranium in Ancient Conglomerates ... *C. F. Davidson* 1048

Reviews:

Genetic Relation of Mineralization to Granitoid Intrusions (Abdullaev) ... *Eugene A. Alexandrov* 1050

The Geological Principles of Prospecting and Exploration of Ore Deposits (Smirnov) ... *Eugene A. Alexandrov* 1055

Sixteen reviews of recent Russian literature on Economic Geology ... *C. F. Davidson* 1056

Elements of Geology (Zumberge) ... 1059

The Petroleum Chemicals Industry, 2nd Ed. (Goldstein) ... 1059

Getting Acquainted with Minerals, 2nd Ed. (English and Jensen) ... 1059

Steinsalz und Kalisalz, Part I (Lotze) ... 1060

Books Received ... *James M. Allen and John W. Salisbury* 1060

Scientific Notes and News ... 1066

Index, Volume 53 ... *Robert B. Miller* 1068

Contents, Volume 53 ... iii

PUBLISHED SEMI-QUARTERLY

Six Dollars Fifty Cents a Year, One Dollar Twenty-five Cents a Copy

THE ECONOMIC GEOLOGY PUBLISHING COMPANY

Printed by Lancaster Press, Inc., Prince and Lemon Streets, Lancaster, Pa.

Second-class postage paid at Lancaster, Pa.

Economic Geology

and the

Bulletin of the Society of Economic Geologists

Issued Semi-Quarterly and sent to subscribers on or about the following dates: February 1, March 15, May 1, June 15, August 1, September 15, November 1, December 15.

Manuscripts for publication should be sent to the Editor, **ALAN M. BATEMAN, at Yale University, Yale Station, New Haven, Conn.** It is requested that contributors exercise care in writing *scientific* and *proper names*. References to other publications should be in accordance with the forms used in the pages of this journal. The manuscript should be typewritten with double space lines and must be preceded by *a brief abstract*. Galley proof will be sent authors only where a request to this effect accompanies the manuscript, or when, in the editor's opinion, the subject matter is such as will require correction by the author.

Reviews should conform to the journal usage. Review Committee: The Editor, C. H. Behre, L. C. Graton, J. T. Singewald, Jr., J. Gilluly, A. F. Buddington, W. H. Newhouse.

Books and Pamphlets for review should be sent to the Editor.

Reprints. Contributors desiring reprints of their papers may obtain them by filling out the order slip which will be attached to the galley proof when it is sent to the author. Provided the order slip is received by the editor, *with the return of the proof*, 50 reprints without covers will be furnished without charge. Reprints of discussions and informal communications are not furnished free of charge except when they exceed four pages in length when 50 will be supplied without charge. Reprints of reviews are not supplied. Additional reprints will be furnished at approximately the rates given in the table below (effective with No. 5) when ordered *in advance of publication*. The rates apply only to plain text, with line engravings. Papers containing folded maps or plates will be more expensive.

The following rates do not include free carriage. *Postage or express must be paid by the author.*

	4 pp. 1–4	8 pp. 5–8	12 pp. 9–12	16 pp. 13–16	20 pp. 17–20	24 pp. 21–24	28 pp. 25–28	32 pp. 29–32	Covers
50 copies.....	$4.20	$6.65	$10.40	$10.85	$14.15	$16.25	$18.70	$19.95	$5.75
100 "	5.00	7.95	12.00	13.30	17.00	19.95	23.30	25.00	7.80
Additional copies per C.	1.70	2.55	4.20	5.00	5.85	7.50	9.15	10.00	3.75

For 500 copies deduct 5%; for 1000 copies or more deduct 10%. For more than 32 pages add cost per schedule to make total. Example: For 44 pages add cost for 32 pages and 12 pages. The 50 copy price is the minimum charge.

Covers: Standard covers are of the same style of type and paper as the cover of the journal, and bear the title of the article and name of its author. Special printing on cover is charged for at the cost of composition.

Plates are $4.20 for the first 50 if printed on one side, and $3.15 per "C" for additional's; printed on both sides, $6.30 for the first 50, and $4.70 per "C" for additional's.

Collotype plates are 8 cents each for each additional reprint over the 50 copies furnished free. Example: An extra 50 reprints containing one collotype plate would cost $4.00; 2 collotype plates, $8.00.

Note: For any reprints requiring additional composition or changes, either in text or cover, an extra charge will be made.

The retail prices of single reprints when available from the office of the Business Manager are as follows:

1–4 pp. 15c	5–8 pp. 20c	9–12 pp. 25c	13–20 pp. 30c	21–28 pp. 35c
29–36 pp. 40c	37–44 pp. 45c	45–52 pp. 50c	53–60 pp. 55c	61–68 pp. 60c

Subscriptions. The price of the journal to subscribers in the United States and its dependencies is $1.25 for a single copy, or $6.50 a year for eight numbers effective July 1, 1953. To subscribers in Canada, Cuba, Mexico, Spain, and countries in Central and South America, except Dutch and French Guiana, the annual rate is $6.80; to other countries, $7.25.

Forwarding. Subscribers wishing their journal to be forwarded to a new address should leave postage for that purpose with the Postmaster at their old address.

Missing numbers will be replaced without charge if claim is made within four weeks after the date of issue of the following number, provided that the neglect to receive them is not due to neglect to arrange for their forwarding.

Remittances should be made payable to the **ECONOMIC GEOLOGY PUBLISHING COMPANY**, and should be mailed to **M. M. LEIGHTON**, Business Manager, Urbana, Illinois, to whom also all **Business Communications** should be addressed.

Foreign Agents. The Technical Bookshop, Salisbury House, London Wall, London E. C. 2, England, British Agents.

Indexed in the Industrial Arts Series.

LANCASTER PRESS, INC., LANCASTER, PA.

ECONOMIC GEOLOGY

AND THE

BULLETIN OF THE SOCIETY OF ECONOMIC GEOLOGISTS

EDITOR: ALAN MARA BATEMAN
Yale University, New Haven, Connecticut

BUSINESS EDITOR: MORRIS M. LEIGHTON
Illinois Geological Survey, Urbana, Illinois

ASSISTANT EDITORS

H. E. MCKINSTRY, *Harvard University*
M. LEROY JENSEN, *Yale University*
JOE W. PEOPLES, *Wesleyan University*
J. D. BATEMAN, Toronto, Ont.
R. H. JAHNS, *California Institute of Technology, Pasadena*

ASSOCIATE EDITORS

D. F. HEWETT
U. S. Geological Survey, Menlo Park, Calif.

A. I. LEVORSEN
Tulsa, Okla.

B. S. BUTLER
Univ. of Arizona, Tucson, Ariz.

W. E. WRATHER
Washington, D. C.

A. N. SAYRE
U. S. Geological Survey, Washington, D. C.

L. C. GRATON
Orange, Connecticut

E. S. MOORE
Univ. of Toronto, Toronto, Can.

GEORGE W. MOREY
U. S. Geological Survey, Washington, D. C.

PER GEIJER
Djursholm, Sweden

P. F. FOURMARIER
Liège University, Liège, Belgium

M. S. KRISHNAN
Ministry Natural Resources and Scientific Research, New Delhi, India

T. W. GEVERS
University of the Witwatersrand, Johannesburg, S. Africa

C. F. DAVIDSON
St. Andrews Univ., Fife, Scotland

J. A. BROGGI
Instituto Geologica, Lima, Peru

TAKEO WATANABE
University of Tokyo, Tokyo, Japan

KONRAD B. KRAUSKOPF
Stanford University, California

A SEMI-QUARTERLY JOURNAL PUBLISHED BY
THE ECONOMIC GEOLOGY PUBLISHING COMPANY

SOCIETY OF ECONOMIC GEOLOGISTS

THE PUBLICATIONS OF WHICH CONSTITUTE
A PART OF THIS JOURNAL

OFFICERS FOR 1958

GEORGE M. SCHWARTZ, *President*

HUGH M. ROBERTS, *Vice President*

HAROLD M. BANNERMAN, *Secretary*, U. S. Geological Survey, Washington 25, D. C.

JOSEPH T. SINGEWALD, JR., *Treasurer*, Johns Hopkins University, Baltimore 18, Maryland

Councilors

1958	*1959*	*1960*
F. S. TURNEAURE	JAMES BOYD	PHILIP W. CHASE
DONALD M. FRASER	DUNCAN R. DERRY	ROBERT M. GARRELS
CHARLES MEYER	W. H. CALLAHAN	EDWARD H. WISSER

Regional Vice Presidents

ARNOLD E. WATERS, JR., Africa.....PER A. GEIJER, Europe
M. S. KRISHNAN, Asia.....E. C. HARDER, North America
CHARLES E. MARSHALL, Australia.....H. C. ALVES DE SOUZA, South America

Executive Committee

GEORGE M. SCHWARTZ, *Chmn.* GILBERT H. CADY JOSEPH L. GILLSON
HUGH M. ROBERTS JOSEPH T. SINGEWALD, JR. HAROLD M. BANNERMAN

President's appointments to Committees for 1958–59

Finance Committee

JOSEPH T. SINGEWALD, JR., *Chairman* OLAF N. ROVE DONALD M. FRASER

Program Committee

JOHN H. MELVIN, *Chairman* M. L. JENSEN J. S. STEVENSON
ROBERT M. GROGAN PETER JORALEMON HAROLD M. BANNERMAN, *Ex-officio*
CARL TOLMAN

Committee on Publications

R. M. FOOSE, *Chairman* JOHN H. FFOLLIOTT ELDRED D. WILSON

Nominating Committee

CHARLES MEYER, *Chairman* JAMES M. HARRISON PHILIP J. SHENON

Admissions Committee

F. S. TURNEAURE, *Chairman* JOHN W. AMBROSE CARL E. DUTTON
FRANK C. FOLEY PATRICK M. HURLEY

Auditing Committee

FRANCIS G. WELLS, *Chairman* A. NELSON SAYRE

Coal Research Committee

ROBERT M. KOSANKE, *Chairman* IRVING M. BREGER
CHARLES E. WIER JAMES M. SCHOPF

Representatives to AAAS.....GEORGE W. WHITE AND W. H. BRADLEY
Representative to National Research Council.....WALTER S. WHITE

ORDER BLANK

FIFTIETH ANNIVERSARY VOLUME
ECONOMIC GEOLOGY
1905-1955

(See page ii)

☐ Enclosed is $..... ☐ Enter my order and send bill

☐ Price to Subscribers $6.00

(including Members, Non-Member Journal Subscribers, and Students whether subscribers or not)

☐ Price to Non-Subscribers to Journal $8.00

To Economic Geology Publishing Company
105 Natural Resources Building
Urbana, Illinois

Mail above copy as checked to:

Name

Street Address

City State Country

ECONOMIC GEOLOGY

AND THE

BULLETIN OF THE SOCIETY OF
ECONOMIC GEOLOGISTS

VOL. 53 DECEMBER, 1958 NO. 8

ISOTOPIC STUDY OF SOME COLORADO PLATEAU ORES *

DONALD S. MILLER AND J. LAURENCE KULP

CONTENTS

PAGE

Abstract 937
Introduction 938
Experimental procedures 939
New experimental data 940
Discussion 942
The uranium-lead age method 942
Apparent ages from the Colorado Plateau 942
Lead isotope abundances of galena 943
Earlier interpretation of the isotopic data 944
Geological and other geochemical data 944
An alternative hypothesis 945
Conclusions 947
Acknowledgments 947
References 947

ABSTRACT

A number of selected uranium ore specimens from several localities have been analyzed for uranium and lead in both pitchblende and galena phases by isotope dilution techniques and the lead isotopic abundance determined. It is shown that the hypothesis of hydrothermal deposition of uranium accompanied by old radiogenic lead from the basement at one time about 60 m.y. ago does not satisfy the isotopic data. A new hypothesis is presented which requires local sources with high U/Th and U/Pb ratios, variable radon leakage, suitable ground water movement, and deposition at the site of H_2S production at low temperature. This hypothesis can explain the age discordances and the lead isotope abundances in galena. It is possible from the isotopic data to have all deposition occurring within the last five million years but it does not preclude other periods of deposition such as in Laramide time. The isotopic ages are apparent ages only

* Lamont Geological Observatory Contribution No. 310.

and bear no direct relation to the time of deposition. The isotopic ratios, however, provide information which may be used to restrict theories of origin.

INTRODUCTION

THE origin of the uranium deposits of the Colorado Plateau has been discussed thoroughly by many authors and several divergent theories have been suggested (14). In addition to geological observations an adequate theory must also satisfy the isotopic relationships. It is the purpose of this paper to present some new critical isotopic data and taking cognizance of published measurements to set forth the limitations that such information places on any theory of origin of the uranium mineralization.

Most of the available lead isotopic measurements are the result of the work of Stieff and Stern whose immediate objective was the definition of the age of the uranium deposition (16, 17, 19). A few additional uranium-lead isotopic analyses were reported by Eckelmann and Kulp (4). The earliest work was done largely on oxidized ore and pitchblende concentrates, which presented many difficulties in interpretation. Later isotopic ratios determined by the U.S.G.S. group were reported (5) on a number of unoxidized hand specimens. The apparent ages varied widely outside of the experimental error and these differences in age have been ascribed (18, 19) to the incorporation of variable quantities of old (i.e., Precambrian) radiogenic lead by the uranium minerals. The primary deposition was interpreted to have occurred at about 60 m.y. ago.

These conclusions have been widely quoted in geological papers in support of a hydrothermal origin of the ores at Laramide time (11, 14). Actually the argument from the published isotopic data for a hydrothermal origin at 60 m.y. ago is not conclusive. It appears to be based on the following reasoning: (1) The Central City pitchblendes in the Front Range are certainly hydrothermal in origin and have a well-defined age of about 60 m.y. (2) Several of the youngest ages of the Plateau ores obtained by Stieff and Stern (5) grouped around 60 m.y. Thus it has been suggested (14) that all of the Plateau ores were hydrothermally emplaced from depth in late Cretaceous or early Tertiary time. Since there need be no necessary relation between the Central City and the Plateau deposits, and since uranium mineralization in the Plateau area as young as Pliocene is known (e.g., Marysvale, Utah, 4), the argument is not strong. Further the hypothesis of old highly radiogenic lead coming from the basement without appreciable contamination with common lead poses certain geochemical problems.

These considerations pointed to the desirability of further investigation of the isotopic geochemistry of the Plateau ores. To study the isotopic variations in detail in an attempt to evaluate the source of the lead and uranium and to detect exsolution effects it is necessary to use polished section—dental drill techniques to obtain sufficiently pure mineral phases. The availability of a new suite of unoxidized mineral specimens and techniques to make isotope dilution and isotope abundance measurements on microgram quantities of lead made it feasible to start such an investigation.

The proper understanding of the isotopic geochemistry of the Plateau ores will contribute substantially to the general problem of sedimentary uranium deposits as well as to uranium-lead geochronometry. For example, if the Blind River and the Witwatersrand uranium occurrences are paleo "Plateau-type" deposits, the isotopic relations in these ore districts can be more readily interpreted once the Colorado Plateau problem is solved. Definition of the

TABLE 1

CHEMICAL AND ISOTOPIC DATA OF URANIUM MINERALS*

	% U	% Pb	Pb204	Pb206	Pb207	Pb208
K-151	16.7 ±0.5	0.495 ±.025	0.0029 ±.0005	1.000	0.104 ±.001	0.110 ±.001
K-152	49.4 ±1.5	1.35 ±.02	—	1.000	0.0558 ±.0008	0.0040 ±.0001
K-153	52.8 ±2.0	0.464 ±.012	0.002	1.000	0.0828 ±.0008	0.0873 ±.0009
K-154	3.18 ±.06	0.070 ±.001	0.010 ±.0002	1.000	0.199 ±.002	0.378 ±.005
K-155	6.03 ±.24	0.148 ±.004	0.0081 ±.0005	1.000	0.172 ±.002	0.317 ±.005
K-167	51.6 ±1.8	1.51 ±.02	—	1.000	0.0521 ±.0005	0.00333 ±.00008
K-168	65.3 ±1.7	0.93 ±.02	0.00158 ±.00004	1.000	0.0773 ±.0009	0.0596 ±.0008
K-169	64.1 ±1.5	1.76 ±.014	—	1.000	0.0617 ±.0005	0.0144 ±.0002
K-174	59.2 ±0.9	0.74 ±.005	0.0005	1.000	0.0616 ±.0007	0.0182 ±.0002
K-177	67.3 ±3.3	1.08 ±.01	—	1.000	0.0542 ±.0008	0.0110 ±.0002
K-177C	60.5 ±3.8	2.79 ±.02	—	1.000	0.0704 ±.0003	0.0478 ±.0004
K-178	36.3 ±0.6	0.84 ±.01	0.0031 ±.0002	1.000	0.133 ±.003	0.122 ±.003

* K-151–155 were not separated as described in this paper. Also K-154 and K-155 are urano-organic material while all others are pitchblende.

reasons for the lack of concordance in the isotopic ages of the plateau uranium minerals, also, will contribute to the explanation of other types of pitchblende deposits that show age discordance.

Experimental Procedures.—The samples were hand specimens of primary black pitchblende, except in two cases of urano-organic minerals. None of the samples had any visible secondary uranium minerals. Several polished sections of each hand specimen were prepared and examined under high mag-

nification. With the aid of small dental drills 20–25 mg samples of pitchblende were taken. The galena was obtained by crushing a piece of a hand specimen which was high in galena content, and then picking out the small galena cubes with fine tweezers. As the chemical analyses of Table 2 show, the separation of galena from pitchblende is good.

The samples are taken into solution with purified nitric or hydrofluoric acid and three aliquots are taken for 1) lead determination by isotope dilution, 2) uranium determination by isotope dilution and 3) lead isotopic composition. A spike of U^{235} is added to the uranium aliquot and a spike of Pb^{208} is added to the lead aliquot. The lead is then extracted by successive washings with dithizone solution and the uranium by the use of Hexone. The detailed extraction procedures are given elsewhere (2). After extraction, the lead samples are precipitated as the sulfide for mounting on the filament in the mass spectrometer. The uranium is put on the filament as uranyl nitrate solution and evaporated to dryness.

TABLE 2

CHEMICAL AND ISOTOPIC DATA OF LEAD MINERALS

	Locality	U/Pb	Pb204	Pb206	Pb207	Pb208
Pb-271	Divide Mine Lisbon Valley Utah	<.011	—	1.000	0.0610 ±.0006	0.0176 ±.0002
Pb-273	Standard Mine Lisbon Valley Utah	0.17	—	1.000	0.0663 ±.0006	0.0365 ±.0003
Pb-274	Lucky Boy Mine Marysvale Utah	—	0.0535 ±.0004	1.000	0.839 ±.004	2.06 ±.02

The samples were analyzed on a 60° Nier-type tube equipped with a surface ionization source and an electron multiplier-vibrating reed collection system. Normally, 20–60 micrograms of lead sulfide mounted on the filament yield a sufficient beam for a good analysis. The total Pb^{+} ion current is usually in the range of 10^{-11} amperes. The precision is approximately 0.5 percent on the Pb^{207}/Pb^{206} and 1.0 percent on the Pb^{208}/Pb^{206} ratios but usually greater than 1 percent on the Pb^{204}/Pb^{206} ratio, since this has a value of about .0005 in most of the analyses reported here.

New Experimental Data.—The chemical and isotopic analyses for samples of pitchblende, urano-organic minerals, and galena are given in Tables 1 and 2. K-151 to K-155 and K-177C were crushed hand specimens, whereas the others were taken by the microtechniques described above. The indicated errors represent the standard deviation during the mass spectrometer runs. The reproducibility from one run to the next is somewhat better as determined on a number of standard lead samples.

In all cases except K-178 the microscopically selected portions of the uranium minerals contained greater than 50 percent uranium. The common

lead content of K-152, K-167, K-169, K-174, K-177 is very low, but even K-168 among the mircroscopically selected samples contains only about 12 percent common lead. Samples K-154 and K-155, which have low uranium concentration and were not microscopically selected, do contain large fractions of common lead. Due to the negligible concentration of thorium (19) in these ores the Pb^{208} is used for the common lead correction. Table 3 gives the calculated ages from the isotopic ratios assuming that the common lead *

TABLE 3

APPARENT U-PB AGES FOR COLORADO PLATEAU SAMPLES
(Ages Given in Million Years)

	Locality	Pb206/U238	Pb207/U235	Pb207/Pb206
K-151	Yazzie 102 Mine Cameron, Arizona	170 ± 13	208 ± 16	680 ± 200
K-152	Mi Vida Mine Lisbon Valley	190 ± 9	200 ± 10	390 ± 50
K-153	Cane Creek Mine Moab, Utah	53 ± 2	55 ± 4	175 ± 50
K-154	Calyx Hole Mine No. 8 Temple Mtn., Utah	84 ± 2	91 ± 5	335 ± 75
K-155	North Mesa Mine No. 9 Temple Mtn., Utah	102 ± 5	107 ± 10	260 ± 75
K-167	Cord Mine Lisbon Valley	205 ± 7	206 ± 7	245 ± 40
K-168	Orphan Mine Grand Canyon	94 ± 4	107 ± 6	400 ± 80
K-169	Mi Vida Mine Lisbon Valley	185 ± 5	208 ± 6	470 ± 60
K-174	Divide Mine Lisbon Valley	85 ± 4	96 ± 6	415 ± 40
K-177	Standard Mine Lisbon Valley	112 ± 7	115 ± 7	215 ± 40
K-177C	Standard Mine Lisbon Valley	294 ± 20	295 ± 20	320 ± 40
K-178	Alyce Tolino Mine Cameron, Arizona	130 ± 4	219 ± 20	1400 ± 200

isotopic composition is that of the average post-Paleozoic ore lead, i.e., $Pb^{204} = .026$, $Pb^{206} = 0.483$, $Pb^{207} = 0.407$, $Pb^{208} = 1.000$ and that the Pb^{208} abundance gives the most precise index of this common lead contaminant. The slight variation in the common leads of the Colorado Plateau is not sufficient to cause appreciable uncertainty in the ages since in most cases the concen-

* The term common lead as used in this paper is that lead whose isotopic composition is controlled and produced by a U/Pb^{204} ratio of approximately 9; i.e., average crustal lead.

tration of the common lead in the pitchblende samples is small. Galena crystals which are associated with uranium mineralizations frequently show a high Pb^{206}/Pb^{204} ratio indicating a mixture of common and radiogenic lead. No correction is made for radon leakage or the incorporation of radiogenic lead into the mineral at the time of formation. These isotopic ages are therefore to be considered "apparent ages" only. As will be seen below, however, these calculated ages provide a useful basis for discussion.

It is seen from Tables 1 and 3 that the errors in the Pb^{206}/U^{238} and Pb^{207}/U^{235} ages are dominated by the chemical analyses in those cases where the common lead correction is insignificant such as K-152, K-167, K-168, K-169, K-174, K-177 and K-177C, but in others that have a significant common lead correction such as K-178 or K-151, the major source of error is the isotopic abundance of the Pb^{207}. The Pb^{207}/Pb^{206} age is highly sensitive to the isotopic ratio in this age range such that a one percent error in the ratio is equivalent to a 25 m.y. error in age. The errors in the apparent Pb^{207}/Pb^{206} ages in Table 3 are largely the mass spectrometer errors in the Pb^{207} measurement even for those samples with considerable common lead content.

Pb-271 and Pb-273 are galena specimens containing the most highly radiogenic lead yet published from the Colorado Plateau.

DISCUSSION

The Uranium-Lead Age Method.—Uranium minerals may be dated in principle by three isotopic ratios, Pb^{206}/U^{238}, Pb^{207}/U^{235} and Pb^{207}/Pb^{206}. If formation of a uranium mineral occurs without the incorporation of lead and if no subsequent chemical alteration takes place, the ages derived from these ratios will agree. They are not strictly independent, however, i.e., given the ratios Pb^{206}/U^{238} and Pb^{207}/U^{235} the Pb^{207}/Pb^{206} ratio is fixed. For young minerals the slope of the Pb^{207}/Pb^{206} ratio versus time curve is small so that the uncertainty in this lead-lead age is large. The principles involved, the decay schemes and the effects of various types of alteration are discussed in detail elsewhere (13).

For the purposes of this paper it is necessary to recount the most relevant causes of discordancy. Radon leakage during the history of a mineral will make the Pb^{206}/U^{238} age low and consequently make the Pb^{207}/Pb^{206} age high while leaving the Pb^{207}/U^{235} age unaffected. Lead loss will always produce the following relationship: Pb^{206}/U^{238} age $< Pb^{207}/U^{235}$ age $< Pb^{207}/Pb^{206}$ age. If the lead loss occurred recently and no other effects are present, the Pb^{207}/Pb^{206} age will be the correct one. If radiogenic lead travels from the source of the uranium and then is redeposited with the uranium the apparent ages will be higher than the true age of deposition and the relative ages will be again Pb^{206}/U^{238} age $< Pb^{207}/U^{235}$ age $< Pb^{207}/Pb^{206}$ age. In this case the Pb^{206}/U^{238} age will be closest to the true age and will be a maximum. The spread in these ages will increase with the increase in the ratio of incorporated radiogenic lead to uranium at the time of deposition.

Apparent Ages from the Colorado Plateau.—The ages on primary unoxidized uranium minerals from the Plateau are summarized in Table 3 (new

work reported here) and by Faul (5, pp. 263, 264). The apparent Pb^{206}/U^{238} ages range from about 50 to about 300 m.y. The ages appear to be independent of the geographical location, the stratigraphic unit in which the ores occur, or the quantity of common lead that is present. Furthermore, some of the Pb^{206}/U^{238} ages appear to exceed the probable age of the rocks in which they are found, e.g., K-167 is in the upper Triassic Chinle formation (about 150 m.y. old).

If the Pb^{207}/Pb^{206} ages were constant the anomalies could be due to recent lead loss. If, on the other hand, the Pb^{207}/U^{235} ages were constant radon leakage could be called on as the sole explanation. Inspection of Table 3 and reference (5), however, show neither of these situations to be the case.

Another important observation is the large spread in Pb^{206}/U^{238} ages in the small Lisbon Valley area (85–210 m.y.). Samples K-177 and K-169, although from different mines, were taken only a few hundred feet apart. These relationships argue against several distinct periods of mineralization.

Finally, it must be noted that the degree of discordance does not increase with apparent age.

TABLE 4

COMMON LEADS FROM THE COLORADO PLATEAU REGION*

Locality	Pb204	Pb206	Pb207	Pb208
Tucson Mountains	0.0543	1.000	0.844	2.07
Conrad No. 1 Mine	0.0536	1.000	0.834	2.04
White Canyon Claims	0.0529	1.000	0.835	2.06
Temple Mountain	0.0539	1.000	0.840	2.07
Marysvale, Utah (Pb-274)	0.0535	1.000	0.839	2.06

* Data from reference (5) except for Pb-274.

Lead Isotope Abundances of Galena.—A number of macroscopic galena samples from the general area of the Colorado Plateau have been analyzed. Some of these results are summarized in Table 4. Except for limited contamination with radiogenic lead in a few cases most of these occurrences show normal common lead.

Samples Pb-271 and Pb-273 listed in Table 2 represent galena that is intimately mixed with the pitchblende at the Divide and Standard Mines. In these cases the amount of common lead is only about 3 and 7 percent, respectively, of the lead in the galena. Although the total quantity of this galena (which carries negligible uranium, Table 2) is small, it is highly diagnostic. The isotopic composition of this nearly pure radiogenic lead indicates a post-Cambrian age for its source.

Another important point with regard to these samples is the similarity of the isotopic composition of the lead in the galena and in the pitchblende (Table 5). This must mean, in the case of the Divide Mine for example, that either the primary deposition of this pitchblende occurred within the last 5 m.y. or that an older deposit recrystallized and exsolved its lead during the last 5 m.y.

Earlier Interpretation of the Isotopic Data.—The interpretation of the published uranium-lead dates proposed as most probable by Stieff and Stern (19) was that the Colorado Plateau ores were emplaced about 60 m.y. ago and that the higher ages were due to the admixture of old radiogenic lead. In view of the new data this interpretation appears unlikely for the following reasons:

1) The basement in this area is probably older than 1000 m.y. based on potassium-argon and rubidium-strontium age determinations done at Lamont and at the Carnegie Institution (1) on many basement rocks surrounding the Colorado Plateau including the Vishnu schist in the Grand Canyon. If uranium was derived from such old rocks and some of its radiogenic lead was carried along and deposited at 60 m.y. ago the difference between the Pb^{206}/U^{238} age and the Pb^{207}/U^{235} age should gradually and regularly increase as the apparent Pb^{206}/U^{238} age increases but this is not observed. For example, if sufficient radiogenic lead from a 1000 m.y. basement source is incorporated into a uranium mineral that formed at 60 m.y. ago, such that the Pb^{206}/U^{238} age was 205 m.y., then the Pb^{207}/U^{235} age would be about 250 m.y. The concordance of K-167 at 205 m.y. shows that this was not the process.

TABLE 5

DATA OF CLOSELY ASSOCIATED GALENA AND PITCHBLENDE LISBON VALLEY

		%206	%207	%208
Divide Mine	K-174 Pitchblende	92.6	5.70	1.68
	Pb-271 Galena	92.7	5.65	1.63
Standard Mine	K-177 Pitchblende	93.4	5.09	1.04
	Pb-273 Galena	90.7	6.01	3.31

2) The samples with the highest concentration of radiogenic lead should give the best approximation to the isotopic composition of the pure radiogenic lead. Pb-271 and Pb-273, which contain only trivial quantities of common lead, have Pb^{207}/Pb^{206} ratios that suggest a post-Cambrian source "age" of 315 ± 35 and 390 ± 40 if the deposition took place recently and there was no radon leakage from the original source.

3) Even if it is assumed that the Divide Mine lead isotope relations (Samples Pb-271 and K-174, Table 5) are a result of exsolution recently, the minimum age of the residue is about 90 m.y. rather than 60 m.y.

4) The transportation of highly radiogenic galena in hot solutions from depth over great distances without extreme contamination with common lead would seem to be difficult.

Geological and Other Geochemical Data.—The geological evidence has been reviewed by McKelvey, Everhart and Garrels (14), Wright (22), Keppler and Wyant (11) and Kerr (12). For present purposes the following salient features must be considered:

1. The ore occurs over a considerable stratigraphic (Pennsylvanian to Tertiary) and geographic range.

2. The ore horizons are generally the permeable units in sequences of continental clastic rocks, including red beds, carbonaceous rocks and acidic tuffs.

3. Ore bodies are generally flat lenses of irregular shape that follow the bedding, but in some cases they are vein-type filling fractures in the sedimentary sequence.

4. The uranium is generally localized near wood or other carbonaceous material and is accompanied by copper, vanadium and iron sulfides.

5. The transporting medium has generally been considered to be ground water and/or dilute hydrothermal solutions. The temperature appears to have been little above room temperature in most cases although elevated temperature are required for the alteration at Temple Mountain and in some of the breccia pipes. Coleman's work (3) on the iron-sphalerite geothermometer at the Happy Jack and Hidden Splendor mines suggests a temperature of deposition less than 138° C.

Additional critical geochemical evidence has recently been supplied by Jensen (9). He has found that the isotopic compositions of the iron sulfides intimately associated with the uranium ores are extremely light, i.e., $S^{32}/S^{34} \cong 23.0$. This establishes the bacterial origin of the H_2S that aided in the uranium deposition (15). The severe localization of the deposits in the permeable zones can then be visualized. The carbonaceous material supplies the food for the bacteria that reduce the soluble sulfate in the ground water, producing a sufficient H_2S concentration to precipitate the low concentration of metals in the water. Since it would appear that the H_2S production must be concurrent with the deposition and since the bacteria cannot operate effectively above 70° C (6) most of the deposition must have occurred near surface temperatures. This also limits the depth of burial at the time of the deposition.

An Alternative Hypothesis.—Consider some mineral phase of the sedimentary sequence that has a high U/Th ratio (at least 10) and a high U/common lead ratio (e.g. 1000). This phase cannot be precisely defined without more experimental work but such a phase might be a) the surface of sedimentary clay particles—the UO_2^{++}/Pb^{++} ratio in ocean water is high, b) the surface of clays formed during the diagenetic destruction of volcanic glass, or c) the surface of fine organic debris scattered through a formation.

From the time that this sedimentary rock forms until the uranium is mobilized this mineral phase must experience variably high radon leakage so that although the *phase* is actually 150 m.y. old, as in the Chinle, the apparent Pb^{207}/Pb^{206} age will be considerably higher. If this phase maintained a high rate of radon loss until recent mobilization of the uranium the Pb^{207}/Pb^{206} apparent age of the radiogenic lead produced would go up to 350 m.y. for 10 percent radon leakage, or to 1300 m.y. for 70 percent radon leakage. Since for carnotite and other fine secondary minerals the radon leakage has been measured as high as 30 percent (8) and the deep sea sediments leak as

high as 60 percent (20), the range of 10–70 percent for this phase does not seem unreasonable.

This radiogenic lead from the uranium phase is small in amount compared with the total rock lead, therefore, the Pb^{206} distributed up and outward due to radon escape would not modify the isotopic composition of the rock lead in any important way.

Next, consider a suitable ground water situation in the last few million years where the surface uranium and lead (mostly radiogenic if the initial conditions are fulfilled) are suddenly mobilized. This might require actual flow rather than stagnation conditions. The uranium and its radiogenic lead would tend to move together at first. If there was a strong concentration of H_2S and organic material in the vicinity, and if the flow rate was sufficiently slow, these elements would tend to redeposit in the same proportion as in the initial *phase*. Depending on local conditions of pH and sulfide ion concentration, etc., however, the ratio of uranium to 150 m.y. old radiogenic lead could vary giving ages that were apparently higher (K-167) or lower (K-174) than 150 m.y. The lead might either be incorporated in the uranium mineral on a submicroscopic level or form distinct disseminated galena crystals as Pb-271 and Pb-273.

The farther the uranium and lead move from the source the greater the degree of common lead contamination. Also the higher the temperature the higher the contamination with common lead, since ground water of hot spring temperatures will alter rock probably releasing some lead from feldspar. The total process of the formation of the average Colorado uranium deposit is then to be visualized as local concentration of uranium from a phase in the sedimentary rocks to which the uranium was weakly bonded. This may have occurred only during the last 5 million years.

The more obvious questions for this hypothesis will now be considered.

1. If the deposition was all recent, why are the apparent ages concentrated in the 50–80 m.y. range? The answer may be that proper ground water conditions prevailed at the beginning of the Tertiary and in the late Cretaceous, as suggested by Kelley (10). K-174 and Pb-271 from the Divide Mine, however, strongly suggest the proper ground water conditions were present in the recent geological past, at least in this area.

2. How can the high Pb^{207}/Pb^{206} ages at the Cameron localities be explained? This requires a high radon leakage in the source phase.

3. Can this hypothesis account for the deposits that contain evidence of hydrothermal activity such as hot water alterations (Temple Mt.), breccia pipe deposits (Orphan) and typical veins (Cane Creek)? The geothermal gradient would have been adequate at certain times so that water greater than 100° C could have flowed upward from the Paleozoic sedimentary rocks up along fractures to cause alterations. Depending on chemical composition these solutions could have formed uranium deposits. The vein fractures and even the evidence for hot water do not require the uranium to have come from the basement. Further, it seems evident from the isotopic data that the uranium and radiogenic lead in the average Plateau deposit did not come from the basement.

4. How is the concordancy of the Pb^{206}/U^{238} and Pb^{207}/U^{235} ages at 50 m.y. (K-153), 115 m.y. (K-177) and 200 m.y. (K-167) explained? The change in the Pb^{207}/Pb^{206} ratio with time is so small from 150 m.y. ago to the present that the mixing of uranium with 150–200 m.y. radiogenic lead will yield essentially concordant ages at 200 or 50 m.y. ago.

CONCLUSIONS

1. The use of microtechniques in sample preparation and isotope dilution for uranium and lead analyses has made it possible to obtain reasonably pure mineral phases from intimately mixed Colorado Plateau uranium ores.

2. The hypothesis that the isotopic age relations in the Colorado Plateau ores can be satisfied by hydrothermal solution from the basement carrying highly radiogenic lead is not likely.

3. Isotopic data on intimately associated galena and pitchblende from the Divide Mine suggest recent deposition (<5 million years) of a typical Colorado Plateau ore.

4. The apparent ages are independent of geography, stratigraphic unit and structural type.

5. A new hypothesis is suggested to account for the isotopic, geochemical and geologic data. It is suggested: (1) the typical Colorado Plateau uranium deposit is formed in the vicinity of organic debris where sulfate reducing bacteria are active, (2) the uranium is carried by ground water solutions, (3) the uranium is mobilized into the ground water from surface phases with high U/Th and U/Pb ratios and (4) this may have occurred at different short intervals, particularly in late Cretaceous and recent times.

6. The apparent ages bear no necessary relation to the actual time of deposition.

ACKNOWLEDGMENTS

This research was initiated due to the encouragement of Professor Paul F. Kerr who procured an unusually fine set of specimens from his own geological investigation in the Plateau, and who pointed out the value of further age work in this region.

The work was expedited by the generous advice and assistance of Mr. James Cobb of the Lamont Geochemical Laboratory who set up the chemical procedures and Mr. Sam Kamhi of the Mineralogy Laboratory who helped with the examination and separation of the samples.

The critical and comprehensive review of the manuscript by Drs. L. R. Stieff and T. W. Stern is gratefully acknowledged. It should be noted, however, they do not concur with the interpretation presented here.

The investigation was made possible by the support of the Research Division of the Atomic Energy Commission under Contract AT(30-1)-1114.

REFERENCES

1. Aldrich, L. T., Wetherill, G. W., and Davis, G. L. 1957, Occurrence of 1350 million-year-old granitic rocks in Western United States: Geol. Soc. America Bull., v. 68, p. 655–656.
2. Cobb, J. C., 1958, Ph.D. Dissertation, Columbia University (in preparation).

3. Coleman, R. G., 1957, Mineralogical evidence on the temperature of formation of the Colorado Plateau uranium deposits: Econ. Geol., v. 52, p. 1–4.
4. Eckelmann, W. R., and Kulp, J. L., Uranium-lead method of age determination, Part II: North American localities: Geol. Soc. America Bull., v. 68, p. 1117–1140.
5. Faul, H., 1954, Nuclear Geology: John Wiley and Sons Inc., New York, 414 p.
6. Feely, H. W., and Kulp, J. L., 1957, Origin of Gulf Coast salt-dome sulphur deposits: Am. Assoc. Petroleum Geologists Bull., v 41, p. 1802–1853.
7. Fischer, R. P., 1955, Uranium-vanadium-copper deposits on the Colorado Plateau: U. S. G. S. Prof. Paper 300, p. 143–153.
8. Giletti, B. J., and Kulp, J. L., 1955, Radon leakage from radioactive minerals: Am. Mineralogist, v. 40, p. 481–496.
9. Jensen, M. L., 1958, Sulfur isotopes and the origin of sandstone-type uranium deposits: Econ. Geol., v. 53, p. 598–616.
10. Kelley, V. C., 1955, Regional tectonics of the Colorado Plateau and relationship to the origin and distribution of uranium: University of New Mexico Publication in Geology, No. 5, 120 p.
11. Keppler, M. R., and Wyant, D. G., 1957, Notes on the geology of uranium: U. S. G. S. Bull. 1046F, p. 126–129.
12. Kerr, P. F., 1958, Emplacement of the Colorado Plateau uranium ores: Geol. Soc. America Bull., v. 69, pp. 1075–1112.
13. Kulp, J. L., Bate, G. L., and Broecker, W. S., 1954, Present status of the lead method of age determination: Am. Jour. Sci., v. 252, p. 345–365.
14. McKelvey, V. E., Everhart, D. L., and Garrels, R. M., 1955, Origin of uranium deposits: Econ. Geol., 50th Anniv. Vol., p. 464–533.
15. Miller, L. J., 1958, The chemical environment of pitchblende, Econ. Geol. v. 53, p. 521–545.
16. Stieff, L. R., and Stern, T. W., 1952, Identification and lead-uranium ages of massive uraninites from the Shinarump Conglomerate, Utah: Science, v. 115, p. 706–708.
17. ————, 1953 The lead-uranium ages of some uraninite specimens from Triassic and Jurassic sedimentary rocks of the Colorado Plateau: U. S. G. S. TEI-322.
18. ————, 1955, Interpretation of the discordant age sequence of uranium ores: U. S. G. S. Prof. Paper 300, p. 549–555.
19. Stieff, L. R., Stern, T. W., and Milkey, R. G., 1953, A preliminary determination of the age of some uranium ores of the Colorado Plateaus by the lead-uranium method: U. S. G. S. Circ. 271, 19 p.
20. Volchok, H. L., and Kulp, J. L., 1957, The ionium method of age determination: Geochim. et Cosmochim. Acta, v. 11, p. 244.
21. Waters, A. C., and Granger, H. C., 1953, Volcanic debris in uraniferous sandstones and its possible bearing on the origin and precipitation of uranium: U. S. G. S. Circ. 224.
22. Wright, R. J., 1955, Ore controls in sandstone uranium deposits of the Colorado Plateau: Econ. Geol. v. 50, p. 135–155.

Economic Geology
Vol. 53, 1958, pp. 949–957

STRUCTURAL RELATIONS AT THE HIDEOUT NO. 1 URANIUM MINE, DEER FLAT AREA, SAN JUAN COUNTY, UTAH [1]

TOMMY L. FINNELL AND WILLIAM B. GAZDIK

CONTENTS

	PAGE
Abstract	949
Introduction	950
General geology	951
Stratigraphy	951
Structure	952
Origin and age of deformation	953
Possible control of ore deposition	955
Conclusion	956
References	956

ABSTRACT

The Hideout No. 1 uranium-copper mine is in sec. 14, T. 36 S., R. 17 E., Salt Lake meridian, about 30 miles N. 86° W. of Blanding, Utah.

Consolidated sedimentary rocks exposed in the vicinity of the mine range in age from Permian to Triassic. The rock units, from oldest to youngest, are: the Cedar Mesa sandstone member, the Organ Rock tongue, and the Hoskinnini tongue of the Cutler formation of Permian age; the Moenkopi formation of Early and Middle (?) Triassic age; and the Shinarump member, the mudstone-sandstone unit, and the Moss Back member of the Chinle formation of Late Triassic age.

The area is on the west flank of the Monument upwarp, and the beds dip 1° to 3° west-southwest. Local monoclines interrupt the regional dip. The prominent joint sets dip steeply and trend N 45° to 55°E, N 35° to 70° W, and N 10° E to N 25° W.

The Hideout No. 1 uranium-copper deposit is in the Shinarump member of the Chinle formation where it fills a stream channel cut in the top of the Moenkopi formation. The apparent relation between the uranium-copper deposit and a low-amplitude monoclinal fold may be explained in the following ways:

1. The beds may have been folded before the Shinarump member was deposited, as suggested by the apparent erosional thinning of the Moenkopi formation along the anticlinal bends; and the flexures may have altered the course and gradient of the Late Triassic streams and perhaps caused thick sediments to accumulate locally.

2. Regardless of whether the beds were folded before or after deposition of the Shinarump member, the local flattening of dip at the Hideout No. 1 channel may have slowed and guided laterally migrating ore solutions into the channel sediments where ore deposits could form.

[1] Publication authorized by the Director, U. S. Geological Survey.

3. Tension joints associated with the flexure in the Moenkopi formation may have been pathways that allowed ascending ore solutions to reach the channel sediments.

Thus, the intersection of channels and flexures may be guides to favorable ground for uranium deposits in the Shinarump member of the Chinle formation.

INTRODUCTION

THE uranium-copper deposit at the Hideout No. 1 mine, sec. 14, T. 36 S., R. 17 E., Salt Lake meridian, Deer Flat area, White Canyon mining district, San Juan County, Utah, is accessible by two graded dirt roads, 13 and 16

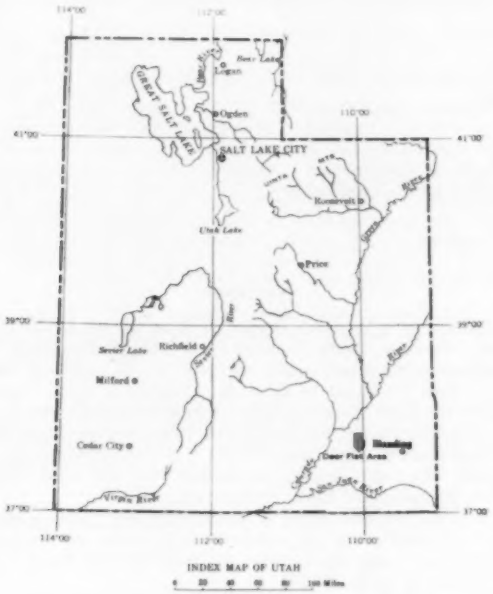


FIG. 1.

miles long, that connect with Utah Highway 95 about 32 and 35 miles west of Blanding, Utah (Fig. 1).

Areal geologic mapping and exploratory diamond drilling at the deposit in 1953 and 1954, revealed variable dips in the vicinity of the mine, and prompted an attempt at closer control on elevations of the most uniform stratigraphic horizon to determine the precise nature of the structure. Existing topographic maps of the area were used in conjunction with a planetable, telescopic alidade, and a graphic locator in a method of geologic mapping that was devised by Varnes (12, p. 1) to facilitate the horizontal and vertical location of geologic contacts in rugged and inaccessible terrains without the use of a rodman. This method indicated the presence of a monoclinal flexure beneath the Hide-

out No. 1 mine, and the closure was delineated more precisely by diamond drill holes and by a transit and stadia survey.

Elmer S. Santos recorded vertical angles and William J. Krummel and Clyde Duren, Jr., surveyed the top of the Hoskinnini tongue with transit and stadia. Their interest in this work is gratefully acknowledged. This work was done by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

GENERAL GEOLOGY

The Deer Flat area is in the Canyon Lands section of the Colorado Plateaus (6, p. 313). The topography of the area is characterized by flat-topped steep-sided mesas separated by deep canyons of intermittent streams that are tributary to the Colorado River.

Consolidated sedimentary rocks exposed in the Deer Flat area range in age from Permian to Triassic (4, 7). The rock units, from oldest to youngest, are: the Cedar Mesa sandstone member, the Organ Rock tongue, and the Hoskinnini tongue of the Cutler formation of Permian age; the Moenkopi formation of Early and Middle(?) Triassic age; and the Shinarump member, the mudstone-sandstone unit, and the Moss Back member of the Chinle formation of Late Triassic age.

Rocks of the Cutler formation are red and grayish-orange sandstones and siltstones that were deposited in continental environments, perhaps near the shore of an epeiric sea. The rocks of the Moenkopi formation consist of red micaceous shales, and red, brown, and yellowish-brown micaceous sandstones in which are preserved abundant ripple marks typical of shallow water deposits. Chinle rocks are fluvial, varicolored, interbedded sandstones, conglomerates, mudstones, and siltstones, with local beds of bentonite that probably represent stream-deposited volcanic ash.

The rocks are part of the west flank of the Monument uplift, and the beds dip 1° to 3° west-southwest and strike north-northwest. Locally, small monoclines modify the regional dip. One set of prominent joints trends N 45° to 55° E, and dips from 65° SE to vertical; another prominent joint set trends N 35° to 70° W, and dips from 85° SW through vertical to 72° NE; a less prominent joint set trends N 10° E to N 25° W, and dips from 80° E to vertical.

The uranium-copper deposit at the Hideout No. 1 mine is in sandstone of the Shinarump member of the Chinle formation where it fills a channel in the top of the Moenkopi formation. The principal ore minerals are uraninite, chalcopyrite, bornite, and chalcocite. They replace fossil plant material, feldspar, and clays, and fill fractures and interstices in the sandstone.

STRATIGRAPHY

The Cedar Mesa sandstone member of the Cutler formation of Permian age consists of crossbedded pale grayish-orange fine-grained sandstone with interbedded red siltstone lenses near the top. The upper 470 feet of the Cedar

Mesa is exposed in the canyons around Deer Flat. The Cedar Mesa sandstone member grades upward into the Organ Rock tongue of the Cutler formation.

The Organ Rock tongue of the Cutler formation comprises about 280 to 300 feet of reddish-brown siltstone and fine-grained sandstone. The Organ Rock tongue apparently grades upward into the Hoskinnini tongue.

The Hoskinnini tongue of the Cutler formation is 75 to 80 feet thick at Deer Flat. It is composed of poorly sorted pale reddish-brown siltstone and very fine- to coarse-grained sandstone. The Hoskinnini is disconformably overlain by the Moenkopi formation.

The Moenkopi formation of Early and Middle(?) Triassic age comprises 215 to 300 feet of ripple-laminated reddish-brown siltstones interbedded with pale-red and yellowish-gray sandstones. An extensive erosion surface separates the Moenkopi from the overlying Shinarump member of the Chinle formation.

The Shinarump member of the Chinle formation of Late Triassic age ranges in thickness from less than 1 foot to 50 feet. It consists of crossbedded gray and yellowish-gray fine- to coarse-grained and conglomeratic sandstone with interbedded mudstone lenses. The Shinarump becomes finer grained toward the top and it grades into the overlying mudstone-sandstone unit.

The mudstone-sandstone unit of the Chinle formation comprises 120 to 160 feet of gray and red mudstone interbedded with gray and brown sandstone. The upper contact of this unit is irregular, and channels in the top of the unit are filled by the Moss Back member.

The Moss Back member of the Chinle formation comprises 45 to 110 feet of crossbedded yellowish-gray fine- to coarse-grained and conglomeratic sandstone with interbedded mudstone lenses. The Moss Back member caps Deer Flat.

STRUCTURE

Strata in the Deer Flat area strike N 23° to 25° W, and dip 1° to 3° west-southwest. Geologic mapping and exploratory diamond drilling in 1953 and 1954, indicated that the ore deposit at the Hideout No. 1 mine is near a change in the regional dip. The change of dip is so subtle that it is obscured on the outcrop by irregularities in the topography.

The top of the Hoskinnini tongue of the Cutler formation and the top of the Moenkopi formation were chosen as the stratigraphic horizons to be contoured. The Hoskinnini tongue is considered to have been essentially flat lying in this area while the Moenkopi formation was being deposited because (1) the Hoskinnini tongue varies only 5 feet in thickness within the area, and (2) the widespread thinly ripple-laminated siltstones of the Moenkopi formation suggest slow deposition in shallow water on extensive tidal flats (8, p. 78–79). Therefore, any structure indicated by contours on the top of the Hoskinnini tongue (base of the Moenkopi formation) presumably has been imposed by deformation subsequent to deposition of the Moenkopi formation. The top of the Moenkopi formation was extensively eroded prior to and during

the deposition of the Shinarump member, and contours on the top of the Moenkopi formation indicate this erosion.

Detailed contours on the top of the Hoskinnini tongue of the Cutler formation, using elevations obtained from 12 diamond drill holes and a transit and stadia survey of the outcrop, show a monoclinal flexure that trends about N 10° W, and show that the ore deposit in the Hideout No. 1 mine is on a narrow structural terrace downdip from the monoclinal flexure (Fig. 2).

Origin and Age of Deformation.—The mode of origin of the monocline is problematical. It may have developed under lateral compressive forces or it may have developed by draping of the beds over a high-angle fault at depth,

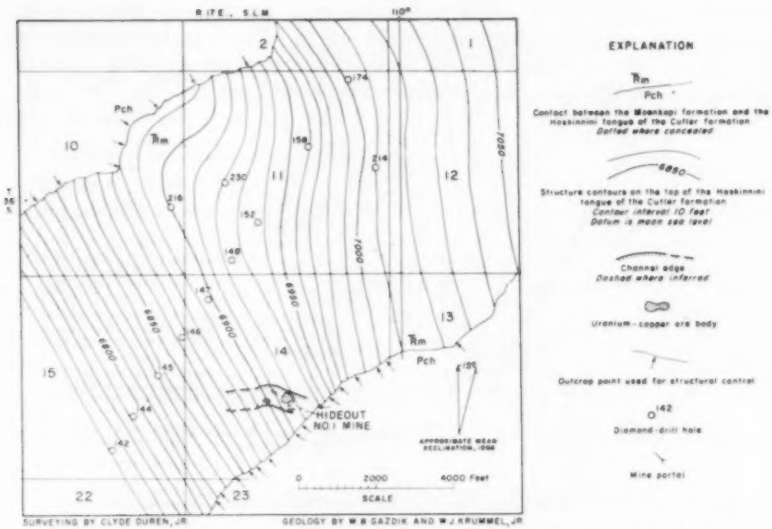

R 17 E., S.L.M.
110°
EXPLANATION
Pch
Contact between the Moenkopi formation and the Hoskinnini tongue of the Cutler formation
Dotted where concealed
Structure contours on the top of the Hoskinnini tongue of the Cutler formation
Contour interval 10 feet
Datum is mean sea level
Channel edge
Dashed where inferred
Uranium-copper ore body
Outcrop point used for structural control
Diamond-drill hole
Mine portal
HIDEOUT NO.1 MINE
APPROXIMATE MEAN DECLINATION, 1958
0 2000 4000 Feet
SCALE
SURVEYING BY CLYDE DUREN, JR.
GEOLOGY BY W. B. GAZDIK AND W. J. KRUMMEL, JR.

FIGURE 2. STRUCTURE CONTOURS ON THE TOP OF THE HOSKINNINI TONGUE OF THE CUTLER FORMATION, DEER FLAT AREA, SAN JUAN COUNTY, UTAH

similar to the fault-fold relations that have been found elsewhere in the White Canyon district.

The Moenkopi formation seems to thin across the anticlinal bend northeast of the Hideout No. 1 mine, suggesting that the flexure may have been present when the Shinarump member of the Chinle formation was deposited (Fig. 3). Crossbedding in sandstone of the Shinarump member that fills the Hideout No. 1 channel dips generally westward, suggesting that the currents which deposited the sands flowed generally westward. If the flexure east of the channel was present before the Shinarump was deposited, it would have provided a steep westward gradient relative to the area farther east (Fig. 2). This increase in grade would have caused the streams flowing across the area to scour their channels down toward local base level. Such scouring would

not be restricted to the steep limb of the flexure, but more probably would extend some distance into the terraces on both sides of the monocline. The deepest part of the Hideout No. 1 channel is between the outcrop and the point where the channel turns to the west (Fig. 2). The point where the channel starts to become more shallow (near the turn) is only about 900 feet from the synclinal bend that defines the western edge of the monocline (Fig. 2). Thus, the channel may have been cut as a result of a steep gradient in the vicinity of the monocline.

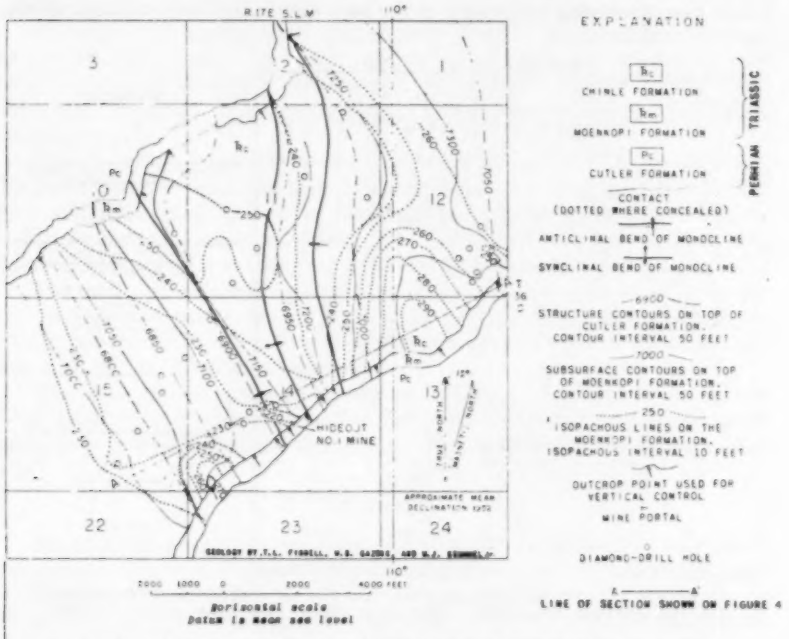

EXPLANATION
CHINLE FORMATION
MOENKOPI FORMATION
CUTLER FORMATION
TRIASSIC
PERMIAN
CONTACT (DOTTED WHERE CONCEALED)
ANTICLINAL BEND OF MONOCLINE
SYNCLINAL BEND OF MONOCLINE
STRUCTURE CONTOURS ON TOP OF CUTLER FORMATION. CONTOUR INTERVAL 50 FEET
SUBSURFACE CONTOURS ON TOP OF MOENKOPI FORMATION. CONTOUR INTERVAL 50 FEET
ISOPACHOUS LINES ON THE MOENKOPI FORMATION. ISOPACHOUS INTERVAL 10 FEET
OUTCROP POINT USED FOR VERTICAL CONTROL
MINE PORTAL
DIAMOND-DRILL HOLE
LINE OF SECTION SHOWN ON FIGURE 4
HIDEOUT NO. 1 MINE
APPROXIMATE MEAN DECLINATION 1972
Horizontal scale
Datum is mean sea level

FIGURE 3.—MAP OF PART OF THE DEER FLAT AREA SHOWING STRUCTURE CONTOURS ON THE TOP OF THE CUTLER FORMATION, SUBSURFACE CONTOURS ON THE TOP OF THE MOENKOPI FORMATION, AND THICKNESS OF THE MOENKOPI FORMATION.

If the monocline affected the streams that cut the Hideout channel, the structure must be older than the Shinarump sediments that fill the channel; and if such folds were present in the Colorado Plateau during deposition of the Shinarump, they may have affected sedimentation in other areas. Pre-Chinle folds in the Moenkopi formation have been described in the Moab district by Baker (1, p. 36, 37, 77); in the area between the Green and Colorado Rivers by McKnight (9, p. 61–62, 129); and along the flanks of the salt anticlines in western Colorado by Stokes and Phoenix (10), and Cater (5).

The flexure may be post-Shinarump in age, but the absence of reliable key beds above the Moenkopi precludes the possibility of proving this. For ex-

ample, the top of the Shinarump member at the Hideout No. 1 channel has a vertical relief of at least 20 feet that cannot be the result of either tilting or folding, but, rather, seems to represent the irregularity of deposition (Fig. 4).

Possible Control of Ore Deposition.—The monoclinal flexure near the Hideout No. 1 mine may have determined the location of the uranium deposit in the channel in a number of different ways: (1) by determining the position and depth of the channel, and thus indirectly influencing the local thickness variations of the Shinarump sediments, (2) by providing local flat dips to slow and guide laterally migrating ore solutions, and (3) by forming tension joints to serve as possible channel ways for ore solutions rising from depth.

The flexure may have affected the stream that cut the channel and caused it to cut deeper near the steep monoclinal limb. If the channels that were established during erosion of the Moenkopi formation guided the aggrading streams that deposited the sediments of the Shinarump member at least until they were filled to the level of the channel banks, any Shinarump sediment

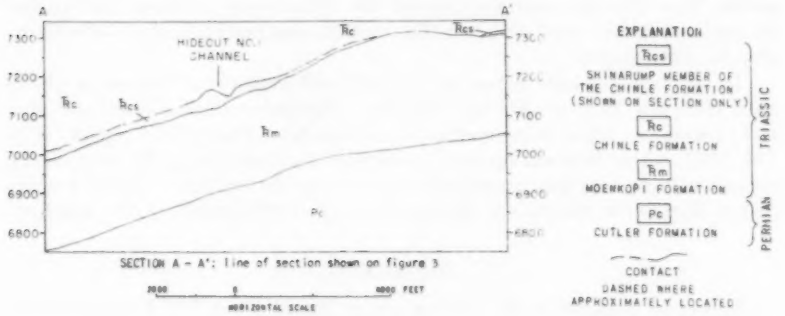


FIGURE 4.—STRUCTURE SECTION SHOWING THE RELATION OF THICKNESS VARIATIONS IN THE MOENKOPI FORMATION AND THE SHINARUMP MEMBER OF THE CHINLE FORMATION TO THE FLEXURES IN THE DEER FLAT AREA, SAN JUAN COUNTY, UTAH.

subsequently added to the area would also add to the thickness of the Shinarump sediments associated with the channels, thus making them thicker than the Shinarump sediments in the areas between channels. The top of the Shinarump member at the Hideout No. 1 channel has a vertical relief of at least 20 feet (Fig. 4), and it is lower near the northeast edge of the channel than it is at the southwest edge. This suggests that deposition of sediments shifted downdip across the channel after the scour was filled.

Uranium ore at the Hideout No. 1 mine occurs with carbonized fossil plant fragments in sandstone beneath mudstone in the lower few feet of the channel sediments. Intensive study of the Shinarump member has revealed only one difference between sediments in the channel and sediments outside of channels—the channel sediments average about 10 feet thicker than non-channel sediments. The ore-depositing solutions seem to have preferred the sandstone in the deep part of channel.

Regardless of whether the beds were folded before or after deposition of the Shinarump member, the terrace at the Hideout No. 1 mine may have slowed the ore solutions and perhaps guided them to the channel where conditions were favorable for ore deposition.

If the ore solutions came from an unknown source at depth, the easiest pathway to the channel sediments would have been along joints. According to many structural geologists, tension joints in folded beds commonly radiate outward from the convex side of the folds (2, p. 98, 102; 11, p. 182–183). This suggests that tension in folded beds may increase upward in anticlines and downward in synclines. If the same inference can be drawn about anticlinal bends and synclinal bends, then it is possible that the northerly trending joints in the Hideout No. 1 mine area are tension joints related to the synclinal bend, and they may extend to considerable depth. If the ore solutions ascended along such joints, they may have moved laterally into the lower part of the Shinarump member because the joints would be poorly developed in the incompetent mudstones of the Chinle above the Shinarump member. No matter how the ore solutions entered the Shinarump, uranium and copper minerals were deposited wherever the solutions reached rocks that were amenable to replacement.

In any case, the intersection of channels with monoclinal flexures might be most favorable locations for ore deposits. Somewhat similar structural control of uranium deposits is reported in the southern Black Hills region (3, p. 348–349), where deposits occur on structural terraces just updip from monoclines and near anticlinal noses superimposed on the terraces, but the authors do not discuss the reasons for the apparent structural control of the deposits.

CONCLUSION

The close association of uranium ore in the Hideout No. 1 channel with a local change in the dip of the underlying rocks indicates that further work is needed to determine if similar relations exist at other deposits on the Colorado Plateau.

U. S. Geological Survey,
Denver, Colo.,
April 17, 1958

REFERENCES

1. Baker, A. A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 841.
2. Balk, Robert, 1937, Structural behavior of igneous rocks: Geol. Soc. America Mem. 5.
3. Bell, Henry, III, Gott, G. B., Post, E. V., and Schnabel, R. W., 1956, Lithologic and structural controls of uranium deposition in the southern Black Hills, South Dakota: *in* Page, L. R., Stocking, H. E., and Smith, H. B., 1956, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U. S. Geol. Survey Prof. Paper 300, p. 345–349.
4. Benson, W. E., Trites, A. F., Jr., Beroni, E. P., and Feeger, J. A., 1952, Preliminary report on the White Canyon area, San Juan County, Utah: U. S. Geol. Survey Circ. 217.
5. Cater, F. W., 1954, Geology of the Bull Canyon quadrangle, Colorado: U. S. Geol. Survey Quadrangle Map GQ no. 33 (with text).

6. Fenneman, N. M., 1931, Physiography of Western United States: McGraw-Hill Book Co., Inc., New York, N. Y.
7. Gregory, H. E., 1938, The San Juan Country: U. S. Geol. Survey Prof. Paper 188.
8. McKee, E. D., 1954, Stratigraphy and history of the Moenkopi formation of Triassic age: Geol. Soc. America Mem. 61.
9. McKnight, E. T., 1940, Geology of area between Green and Colorado Rivers, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 908.
10. Stokes, W. L., and Phoenix, D. A., 1948, Geology of the Egnar-Gypsum Valley area, San Miguel and Montrose Counties, Colo.: U. S. Geol. Survey Oil and Gas Inv. Map 93.
11. Turner, F. J., 1948, Mineralogy and structural evolution of the metamorphic rocks: Geol. Soc. America Mem. 30.
12. Varnes, D. J., 1946, Geologic mapping by means of graphic locator: U. S. Geol. Survey Circ. 12.

Economic Geology
Vol. 53, 1958, pp. 958–965

THE INFLUENCE OF IONIC SUBSTITUTION ON THE STABILITY OF MICAS AND CHLORITES[1]

R. C. DEVRIES[2] AND RUSTUM ROY

ABSTRACT

The equilibrium stability temperatures of various micas were determined and compared at the same water pressure. Dioctahedral minerals are considerably less stable thermally than trioctahedral phases. Substitution in the octahedral layer of Ni^{2+} for Mg^{2+} makes very little difference, and Ga^{3+} for Al^{3+} in the tetrahedral position strongly lowers stability temperatures.

In the chlorites, Cr^{3+} will only enter the structure if balanced by an equal amount of aluminum; and a drastic reduction in stability maximum is caused by the substitution. In this structure also Ni^{2+} exchange for Mg^{2+} causes very little change in stability temperature. These data are discussed from a crystallochemical viewpoint.

INTRODUCTION

SINCE Pauling's classic work on the ionic arrangement in the layer lattice minerals, these structures have become excellent examples for demonstrating the variety of ionic substitutions and resulting property changes possible in silicate structures. The micas and the chlorites with three and two different cation positions, respectively, are both widely distributed hydroxyl-bearing minerals, and a study of their thermal stability as a function of composition may be expected to yield information pertinent to both interpretive petrology and crystal chemistry. This investigation considers the stability under hydrothermal conditions of both synthetic (hydroxyl) and natural micas and chlorites.

EXPERIMENTAL

Hydrothermal techniques, which have been described frequently in the literature, were used in this laboratory for these studies. In this particular case, the "test tube" type of pressure vessel was used in conjunction with a jack type pump throughout. Pressure was measured with Bourdon type gauges and was checked at frequent intervals during each run. Temperature control was maintained with commercially available controllers and the temperatures were measured with chromel-alumel thermocouples. The accuracy of the temperature and pressure measurements is about $\pm$ 10° C and $\pm$ 3%, respectively.

Both natural minerals and synthetic compositions (glasses, gels and oxide mixtures) were used as starting materials. These materials were contained

[1] Contribution No. 56-75, The College of Mineral Industries, The Pennsylvania State University, University Park, Pennsylvania.

[2] R. C. DeVries is now at the Research Laboratory, G. E. Company, Schenectady, N. Y.

in gold envelopes during the run. Details of the methods of preparing mixtures, and other experimental procedures have been described by Roy and Osborn (4); Roy (1956); Roy and Roy (3).

After being held at temperature and pressure for periods of several days to a few weeks and subsequent quenching, the phases were identified by optical and X-ray techniques. The basal spacings were measured from traces on a GE-XRD 3 diffractometer at 1/5° 2θ per minute using CuK-radiation and quartz as a calibrant; these data are considered precise to $\pm$ 0.01 2θ.

The data are presented at only one pressure (15,000 psi $\sim$ 1000 atm) for the micas, and for a narrow range near the same pressure for the chlorites. The p-t slopes were not precisely determined, though none of the samples showed any evidence that the slope was not similar to that for analogous reactions in the same general temperature r .nge (i.e., showing a difference of from 50° to 100° C, depending on the temperature, between the equilibrium temperatures at 5000 to 30,000 psi, respectively.

TABLE 1

1. In the Phlogopite Structure:	$KMg_3AlSi_3O_{10}(OH)_2$
a. Ni^{2+} for Mg^{2+}	Successful
b. Ga^{3+} for Al^{3+}	Successful
2. In the Margarite Structure:	$CaAl_2Al_2Si_2O_{10}(OH)_2$
a. Ba^{2+} for Ca^{2+}	Unsuccessful
b. $3Mg^{2+}$ for $2Al^{3+}$	Mica (plus other phases)
c. $Ti^{4+} + Mg^{2+}$ for Al^{3+}	Unsuccessful
d. Ti^{4+} for Si^{4+}	Unsuccessful
3. In the Chlorite Structure:	$Mg_{6-n}Al_nAl_nSi_{4-n}O_{10}(OH)_8$
a. Cr^{3+} for Al^{3+} in amesite	Successful ($n = 2$)
b. Ni^{2+} for Mg^{2+} in clinochlore	Successful ($n = 1$)
c. Cr^{3+} for Al^{3+} in clinochlore	Unsuccessful ($n = 1$)

In Table 1 are listed the substitutions tried with remarks on the degree of success.

RESULTS AND DISCUSSION

Micas

In Figure 1 is shown a schematic representation of the mica structure with the substitutions to be considered and the thermal stability of each phase at a water vapor pressure of 15,000 psi. The data for paragonite are from earlier work in this laboratory (5) and those for Mg-phlogopite from Yoder and Eugster (8). With the exception of the muscovite and the Ni- and Ga-phlogopites all starting materials were natural minerals. The only synthesis of a mica with Al^{3+} in the six-fold site was that of muscovite; the brittle mica, margarite, could not be synthesized under the conditions used. An attempt to synthesize a seybertite ($CaMg_3Si_2Al_2(OH)_2O_{10}$) from the stoichiometric composition resulted in a mica layer lattice structure plus other phases indicating that the pure phase desired had not been obtained.

The failure to synthesize a margarite is consistent with the usual difficulty in synthesizing silicates with Al^{3+} in six-fold coordination. However this failure is incompatible with the successful synthesis of muscovite and paragonite, and the additional factor of the control exercised by the structure concerned is all too frequently neglected: In this case the polarizing power of the large monovalent ions is weak enough to allow the Al^{3+} to satisfy its coordination more easily, by distortion of the network if necessary. In margarite, however, the competition is with Ca^{2+}, and in this case apparently the sixfold Al-O coordination is not sufficiently close to the ideal octahedral requirement to be realized as easily.

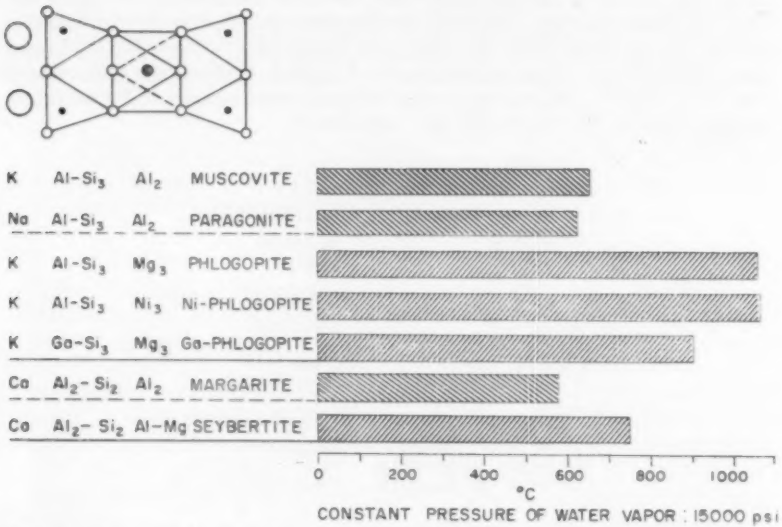

K Al-Si3 Al2 MUSCOVITE
Na Al-Si3 Al2 PARAGONITE
K Al-Si3 Mg3 PHLOGOPITE
K Al-Si3 Ni3 Ni-PHLOGOPITE
K Ga-Si3 Mg3 Ga-PHLOGOPITE
Ca Al2-Si2 Al2 MARGARITE
Ca Al2-Si2 Al-Mg SEYBERTITE
0 200 400 600 800 1000
°C
CONSTANT PRESSURE OF WATER VAPOR : 15000 psi

FIG. 1. Decomposition temperatures of various micas at a constant pressure of water vapor. Data for paragonite and Mg-phlogopite are from the literature.

Stability of Trioctahedral and Dioctahedral Micas.—There are several observations to be made from the data of Figure 1. The first is the greater stability of the trioctahedral micas as compared to dioctahedral micas. This is consistent with the stability (all given for $\sim$ 1000 atm) of other layer lattice silicates in which either only two-thirds or all of the octahedral sites are occupied:

Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$	575° C
Talc	$Mg_3Si_4O_{10}(OH)_2$	780° C
Kaolinite	$Al_2Si_2O_5(OH)_4$	405° C
Chrysotile	$Mg_3Si_2O_5(OH)_4$	500° C

If the role of vacancies in diffusion processes is considered, it is tempting here to ascribe the reason for this higher stability of the trioctahedral types

in the 1:1 structures to some mechanism in which the lack of vacancies and the consequent lower diffusion rate is operative. But in the case of the micas there is the additional complication that the products of decomposition are different since the dioctahedral and trioctahedral mica compositions are in three- and four-component condensed systems, respectively. Hence a different equilibrium is involved in the breakdown of each. However, the decomposition of all micas involves first, the loss of structural water, and it is convenient to think of the stability of a mica in terms of the total strength of the cation-OH bonds. The greater thermal stability of the fluorine micas is consistent with this approach (2).

A reasonable picture of the difference may also be obtained if one considers the probability of the repulsion of the protons in the hydroxyls towards the unoccupied cation holes in the framework of the dioctahedral clays. The elimination of H_2O is facilitated by this arrangement more than by the presence of more symmetrical (OH) ions necessitated by the filling of all the octahedral cation positions by divalent ions. By the same type of reasoning the incongruent melting of fluorine muscovite (or its subsolidus dissociation) may be explained by the greater anisotropy of bond strengths in the structure as compared to those in the essentially congruently melting fluorine phlogopite.

Consistent with the greater stability of trioctahedral micas is the greater stability of seybertite, in which Mg^{2+} is present with Al^{3+} in the octahedral sites, as compared to margarite with only Al^{3+} in this position.

Effect of Ni^{2+} for Mg^{2+} Substitution.—It is interesting that the substitution of Ni^{2+} (non-noble gas ion) for Mg^{2+} (noble gas ion) in the phlogopite lattice has so little effect on the thermal stability. Similar behavior has been found in the serpentines (3). The basal spacings of the Ni- and Mg-phlogopites are 10.13 and 10.17Å, respectively.

Effect of Ga^{3+} for Al^{3+} Substitution.—A third observation is the lowered stability of the phlogopite in which Al^{3+} has been replaced by Ga^{3+} in the four-fold position.[2] In this case the strength of the hydroxyl bond cannot be appealed to and the limitations of the bond strength picture in this structure become obvious unless the change is attributed to effects of the Ga^{3+} beyond the first coordination sphere. However, this behavior may be an expression of the weaker Ga-O bond compared to the Al-O bond, and would be consistent with generally lower reaction temperatures in dry or wet equilibria resulting from substitution of components of lower "stability." Thus it could be expected that substitution of the lower melting Ga_2O_3 for Al_2O_3 in the system K_2O-MgO-Al_2O_3-SiO_2 would result in lower thermal stability of comparable compositions. This approach seems more reasonable in explaining how a smaller substitution in the four-fold position is seemingly more effective in altering mica stability than substitutions in the six-fold position.

Relation to Dry Equilibria.—The anhydrous compositions of paragonite, muscovite and margarite can be represented in their respective ternary

[2] Presumably, the decomposition reaction is the same as that in the case of phlogopite: leucite + forsterite + orthorhombic kalsilite, though the kalsilite has not been unequivocally identified in the products.

systems as lying on joins connecting corundum and the appropriate feldspar (Fig. 2). Two of these joins, albite-corundum and anorthite-corundum, actually represent equilibrium conditions in the dry systems. However, as shown in Figure 2, the join K-feldspar-corundum does not represent a stable assemblage in the equilibrium diagram (6); rather, the anhydrous muscovite composition is supposed to yield feldspar, mullite and leucite at equilibrium. Therefore, if the K-feldspar and corundum coexist, either they do so metastably, or somewhere above about 800° C the reaction feldspar + corundum ⇄ mullite + leucite occurs.

It was found in this investigation that natural or pre-formed muscovite did decompose under hydrothermal conditions to K-feldspar and corundum,[3] but the synthetic starting materials (gels, glasses and mechanical mixtures of oxides) always resulted in the high temperature assemblage above the

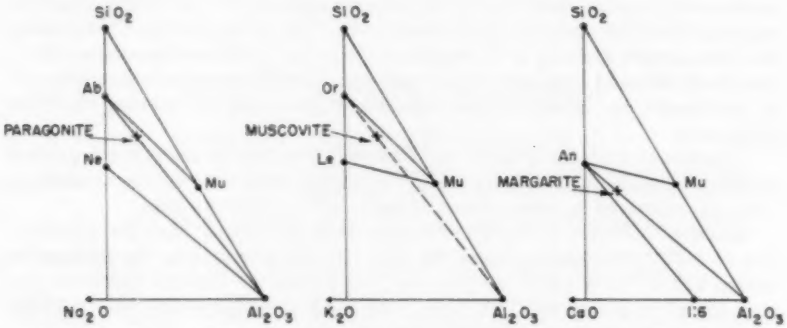


FIG. 2. Compatibility relationships in the ternary systems applicable to the anhydrous compositions of paragonite, muscovite and margarite. Ab = albite, Ne = nepheline, Mu = mullite, Or = orthoclase, Le = leucite, An = anorthite, 1:6 = CaO. 6 Al_2O_3.

decomposition temperature of muscovite. It is apparent that the synthetic materials have a predisposition toward the high temperature assemblage, because of the Al-Si randomization. In the muscovite the octahedral layer provides a ready-made corundum base, while the $AlSi_2$ tetrahedral layer is already in the right ratio for feldspar. This can be quite easily seen if one considers the schematic representation of the mica structure as shown in Figure 1. It is obvious that the breaking of the OH bond separates the dioctahedral micas *in situ* for the formation of a feldspar and corundum without the necessity of long range diffusion of ions. This would be the simplest reaction and probably takes place for both margarite and paragonite. A similar situation has been cited for the decomposition of illites (1). A discussion of the phase relations and the importance of structural control as

[3] Amply corroborated since by the extensive work of Yoder and Eugster, Geochim. Cosmochim. Acta, v. 8, p. 225 (1955).

well as the observations of Sundius and Byström (7)[4] on the dehydration of natural muscovites has recently been developed and studied in greater detail by Roy (unpublished).

Comparison of Ca- vs. K- and Na-Micas.—Of further interest is the fact that Ca-mica has a lower thermal stability than either alkali mica, but has a higher hardness (than either). Here the contrapolarization concept of Goldschmidt can be applied reasonably to both properties. Thermally, the attraction of Ca^{2+} for the $(Al_2Si_2O_8)^{2-}$ group is stronger than in the case of the alkalies on the basis of field strengths. This tends to form feldspar units out of the tetrahedral layers + the interlayer Ca^{2+} ions, with the octahedral layer cleaving off separately. Physically, this same attraction (now between layers in the mica) tends to make the bond distribution less anisotropic and the result is a harder and more brittle mica.

The effect of increasing the lattice spacing on substitution of Mg^{2+} for Al^{3+} is shown by the basal spacings of margarite (9.45Å) and seybertite and brandisite (9.54Å). The purity of the margarite is indicated by the fact that as far as optical and X-ray techniques could resolve only corundum and anorthite formed on heating above the decomposition temperature (550° C). Olivine and spinel were present in the decomposition products of seybertite and brandisite.

Chlorites

In Figure 3 the chlorite compositions that were studied are listed with maximum stability temperatures under hydrothermal conditions. All but kaemmererite are synthetic compositions. Attempts were made to replace: a) one-half and b) all of the Al^{3+} by Cr^{3+} in the amesite composition ($4MgO.2Al_2O_3.2SiO_2.4H_2O$) and c) to effect complete substitution of Cr^{3+} for Al^{3+} in the clinochlore ($5MgO.Al_2O_3.3SiO_2.4H_2O$) composition. The substitutions (b) and (c) above were unsuccessful; the first, (a) yielded a well-crystallized 14Å chlorite (RI (basal section): $1.592 \pm .004$, white light) for which there is some evidence that some chromium entered the structure although the exact amount could not be established. This evidence is as follows:

1. The products was predominantly light grey in contrast to the usual bright green product observed when any appreciable amount of uncombined Cr_2O_3 was present;

2. No Cr_2O_3 or picrochromite could be detected by X-ray methods although optical examination reveals a small amount of free Cr_2O_3;

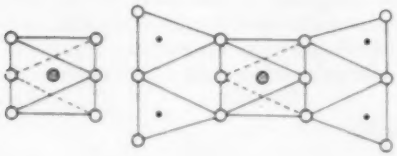
3. The basal spacing measured from the (004) line is 3.53Å; this can be compared with 3.51Å for the Cr-free 14Å amesite. This spacing (3.53Å) is quite distinct from the spacing for clinochlore—the only Cr-free chlorite which could form. Such evidence indicates a Cr content[5] for the synthetic

[4] The path of crystallization of the muscovite composition given by these authors based on Schairer and Bowen's phase diagram is incorrect, due to the curious omission in the latter paper of one Alkemade line.

[5] A value of 3.55Å for the Cr-chlorite, kaemmererite, which contains about 5% by weight Cr_2O_3, is obtained, but the significance of this is questionable due to other compositional variations in these natural minerals.

amesite of the order of half the R_2O_3 in amesite. Crystallochemically this is precisely what should be anticipated since all the Cr^{3+} must be in octahedral coordination (no exceptions have yet been described); and hence an equal amount of Al_2O_3 is required for tetrahedral substitution.

The chrome-bearing chlorite minerals, kaemmererite and kotschubeite, decompose at about 500° C over the pressure range of 10,000 psi to 30,000 psi The first appearance of euhedral olivine crystals is readily detected opt.cally. These crystals grow larger with increasing pressure. Talc is the secoind decomposition product detected and then a spinel phase. This assemblage is commonly obtained in the MgO-Al_2O_3-SiO_2-H_2O system also although it is probably metastable with respect to the assemblage cordierite-spinel-olivine. After hydrothermal treatment below the decomposition temperature, the original abnormal blue birefringence of the chlorite could no longer be seen. This would suggest that the abnormal blue birefringence



				MAXIMUM TEMPERATURE (°C)	BASAL SPACING (A°)
Mg_2-Al	Al-Si_3	Mg_2-Al	AMESITE	680	14.04
Mg-Al-Cr	Al-Si_3	Mg-Al-Cr	Cr-Al AMESITE	> 620	14.12
Mg-Al-Cr	Al-Si_3	Mg-Al-Cr	KAEMMERERITE	525	14.20
$Mg_{2.5}$-$Al_{0.5}$	$Al_{0.5}$-$Si_{3.5}$	$Mg_{2.5}$-$Al_{0.5}$	CLINOCHLORE	700	14.34
$Ni_{2.5}$-$Al_{0.5}$	$Al_{0.5}$-$Si_{3.5}$	$Ni_{2.5}$-$Al_{0.5}$	Ni-CLINOCHLORE	700	14.25

FIG. 3. Decomposition temperatures and basal spacings of various chlorites.

is caused by the presence of a valence state (divalent iron?) which is altered (oxidized to trivalent iron,?) by the relatively mild hydrothermal treatment. The decomposition temperatures found are markedly lower than for the pure Al^{3+} end member, but the data do not allow a clear comparison of the effect of Cr^{3+} for Al^{3+} in synthetic amesite. It is not well enough established to ascribe it to the fact that Cr-OH bonds can be expected to be much weaker than the Al-OH counterpart.

It will be noted that as in the phlogopites the complete substitution of Ni^{2+} for Mg^{2+} in the clinochlore structure does not markedly affect its thermal stability.

SUMMARY

This study of some substitutions in the mica and chlorite families serves to emphasize the difficulties in predicting the stability relations among phases purely on crystal chemical grounds, based on earlier knowledge.

The authors could find no simple explanations of the greater influence of one Ga^{3+} atom in the tetrahedral layer than three Ni^{2+} ions in the octahedral, on the stability of phlogopitic micas. Similarly the abnormally low temperature of dissociation of the chromium containing chlorite could not easily have been predicted. Thus, it appears that the empirical observations recorded on this study may themselves help to provide a growing body of data from which theoretical deductions or empirical rules may be built.

ACKNOWLEDGMENT

This study was supported by the U. S. Army Signal Corps Engineering Laboratories, under Contract Da 63099, and appeared in reports to that agency dated from July 1952 to October 1956. It was presented at the Annual Meeting of the Geological Society of America in New Orleans, November 1955.

DEPARTMENT OF GEOPHYSICS AND GEOCHEMISTRY,
THE PENNSYLVANIA STATE UNIVERSITY,
UNIVERSITY PARK, PA.,
April 17, 1958

REFERENCES

1. Grim, R. E., and Bradley, W. F., 1940, Am. Ceramic Soc. Jour., v. 23, p. 242.
2. Noda, T., and Sugiyama, S., 1943, Jour. Soc. Chem. Ind. Japan, v. 46, p. 921–923.
3. Roy, D. M., and Roy, R., 1954, Am. Mineralogist, v. 39, p. 957.
4. Roy, D. M., Roy, R., and Osborn, E. F., 1950, Am. Ceramic Soc. Jour., v. 33, p. 153.
5. Sand, L. B., Roy, R., and Osborn, E. F., 1954, Am. Mineralogist, v. 39, p. 341. Abstr.
6. Schairer, J. F., and Bowen, N. L., 1955, Am. Jour. Sci., p. 253, p. 681.
7. Sundius, N., and Byström, 1953, Am. M. Trans. Brit. Cer. Soc., v. 52, p. 632.
8. Yoder, H. S., and Eugster, H. P., 1954, Geochim. and Cosmochim. Acta, v. 6, p. 157.
9. Yoder, H. S., and Eugster, H. P., 1955, *Ibid.*, v. 8, p. 225.

Economic Geology
Vol. 53, 1958, pp. 966–1003

BANDED PYRITE DEPOSITS OF MINAS CARLOTA, CUBA

PATRICK ARTHUR HILL

CONTENTS

PAGE

Abstract 967
Introduction 967
History 968
  Written accounts 968
  Exploitation 969
General geology 971
Macroscopic description of the ores 973
Microscopic study of the ores 973
  Gossan 5, drillhole 8, slide 12 977
  Gossan 5, drillhole 8, slide 11 977
  Gossan 3, drillhole 6, slide 2 978
Nature of the ore and gangue minerals 978
  Paragenesis 978
  The anomalous quartz 980
  Nature of the pyrite 981
  The possible significance of pyrite crystal form 981
    Statement of the problem 981
    The influence of composition 982
    The influence of associated minerals 983
    Crystal form at Carlota 984
Chemical analyses 984
  Experimental procedure 984
  Interpretation 984
The nature of the orebody 988
  General remarks 988
  Temperature of pyrite formation 988
  Direction of mineralization 989
  The geological association of the ore 990
  The banding of pyrite ores 991
    A review and classification 991
    The banding at Carlota 992
Origin of the ore 993
  A possible syngenetic origin 993
  A possible syngenetic-epigenetic origin 995
  An epigenetic origin 995
    Gravity separation 995
    Contact metasomatism 996
    A hydrothermal origin 997
    Synopsis of mineralization 998
      Stage 1 998
      Stage 2 998

Stage 3 998
Stage 4 998
Stage 5 998
Acknowledgments 998
References 999
Appendix 1002

ABSTRACT

The orebodies of Minas Carlota are steeply dipping pyrite lenses arranged *en echelon* in isoclinally folded limestones. The lenses occur at faulted contacts with serpentinite or in tensional fold areas.

Mineralization was in the approximate order: (1) sphene, picotite; (2) actinolite, albite; (3) quartz, calcite, chlorite; (4) anomalous quartz, rutile, sericite; (5) fine-grained pyrite; (6) coarse pyrite; (7) chalcopyrite; (8) sphalerite; (9) galena. (1) represents a magmatic or contact-metamorphic phase, (2) dynamic metamorphism, (3) a phase immediately preceding pyritization, while (4) overlapped with (5) and (6). Early pyrite (5) originated by replacement of limestone along graphitic laminae concurrently with rock folding, at a suggested temperature of 600° C. Later pyrite (6) formed at lower temperatures as a space-filling. (7), (8) and (9) comprise less than 10 percent of the ore. Post-ore deformation is limited to marginal ore and represents differential adjustment to late faulting.

Chemical studies suggest that low gold, cobalt and nickel values are contained in the fine-grained pyrite.

Of pyrite crystals the cube is the only euhedral form in gangue (?), whereas in the late pyrite (6) cubes and cubes modified by a possible octahedral zone are present. A search of the literature suggests that: i) the cube is the commonest form of pyrite, ii) the cube is dominant in veins containing sericite, chlorite and carbonate, iii) the cube where associated with anomalous fringing quartz has grown contemporaneously with rotation and rock movement, iv) the pyritohedron develops at higher temperatures than the cube, v) pyrite octahedrons from meosthermal deposits invariably contain slight manganese values.

The ores are regarded as hydrothermal. Their occurrence adjacent to serpentinite is considered an indication of structural control rather than of contact metamorphism. Crystallization of the upper portion of the magma may have led to sulfide enrichment at depth. Renewed earth movement forced the ore fluids upwards along the flanks of the intrusions.

Serpentinization preceded pyritization. A decrease in volume on serpentinization created tensional areas in the limestone which were infiltrated by the ascending ore fluids. Mineralization and serpentinization are believed closely related in time and may be post-Jurassic, pre-Maestrichtian.

The Carlota orebodies are parallel to regional structure. An investigation into the geotectonic implications of such orebodies is long overdue.

INTRODUCTION

In 1950, a threatened world shortage of native sulfur (brimstone) led to an extensive search for alternative sources of supply. Among the many pyrite deposits re-examined were those of the Mina Carlota in Cuba, a mine inactive since 1921.

Mina Carlota is approximately 22 miles southeast of Cienfuegos in the

northwest Trinidad Mountains. Access to the mine is via Cumanayagua (Fig. 1).

HISTORY

Written Accounts.—Written information on Carlota is limited. No published accounts exist. Unpublished reports are few and not generally available; most were written some forty years ago when the mine was in operation.

The earliest mention of a pyritic deposit south of Cumanayagua is in the sixteenth century (14). The ore is first described by Holden 1913–1915

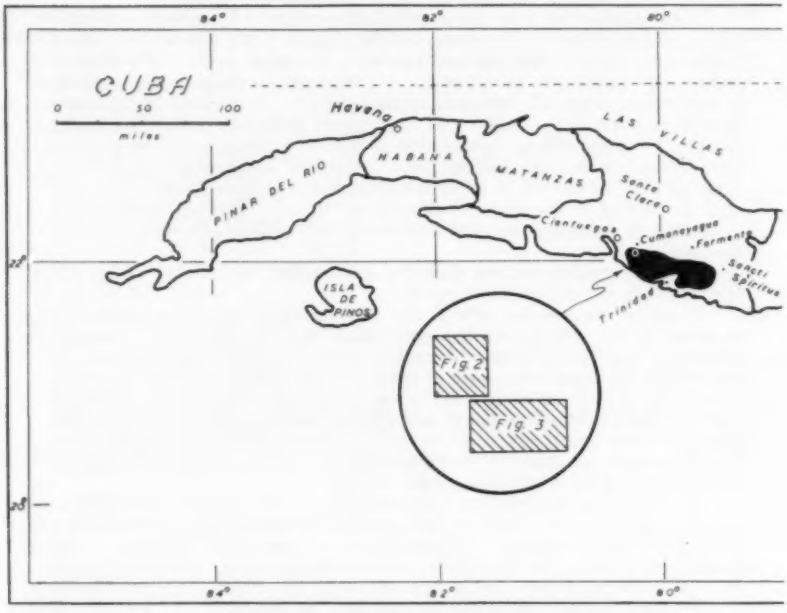


FIG. 1. Location of Minas Carlota (white circle). Trinidad Mts. in black.

(43, 44, 45). The reports of Yeatman and Berry (99, 100) followed, supplemented with petrographic descriptions by C. P. Berkey. Although these accounts mention the gossans and contain chemical analyses, they deal primarily with mining economics and do not discuss the origin of the ore. In 1928 Allende (3) wrote briefly on the Carlota district but contributed nothing original.

In 1951 Wilson (98) relocated the gossans of former reports. During the same year Hill tried to correlate drillcore samples with surface gossans. During his second visit (1952–53) he mapped the gossans in detail (42). A full account of the gossans of Minas Carlota is in preparation.

Exploitation.—Exploitation of the pyrite far antedates written reports. The Victoria orebodies are reputed to have been worked as early as the 1860's by miners from France or Spain. As a result the Victoria gossans are pock-marked by pits, shafts, adits and trenches.

In 1908 the property passed to the Phoenix Company (45) which: "did some surface trenching in the gossan cropping, drove several adits, drifts and

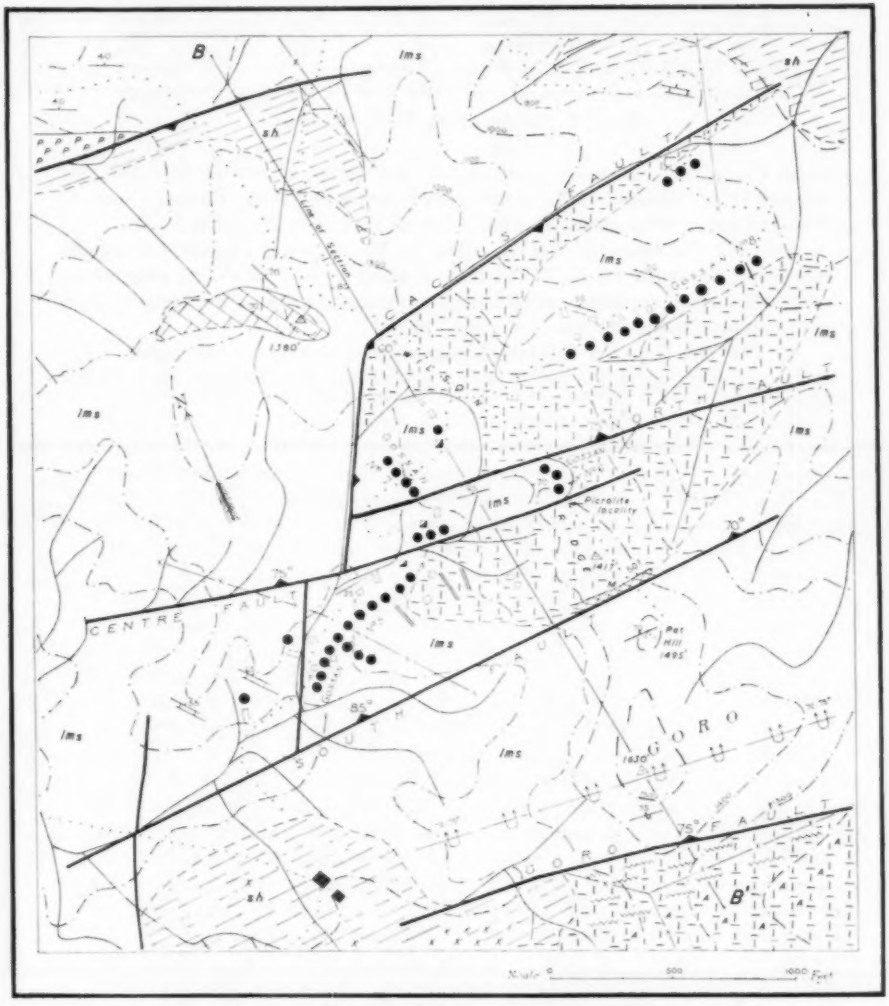


FIG. 2. Geology of the Victoria area (for legend see Fig. 3B).

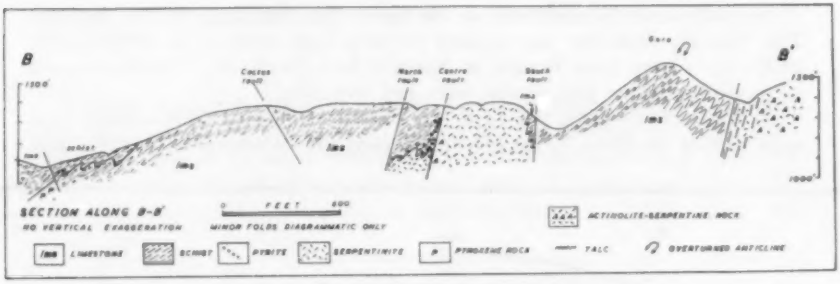


FIG. 2A. Section along B–B′ of Figure 2.

small shafts, and made seven churn and core drills; a total of 1415 feet, the deepest being 380 feet. The deepest shaft, presumably the Phoenix, went to 160 feet and a cross-cut at this point cut 46 feet of clean pyrite."

In 1913 the property was acquired by the Davison Chemical Company which put down a total of 10,718 feet of diamond drill holes, constructed an adit, and sank new shafts. Operations commenced at the mine early in 1919 and employed some 500 men but ended in 1921.

In 1946 the Freeport Sulphur Company bought the property rights. The ensuing drilling program of 1951–52, comprised 38 holes totalling 11,942 feet.

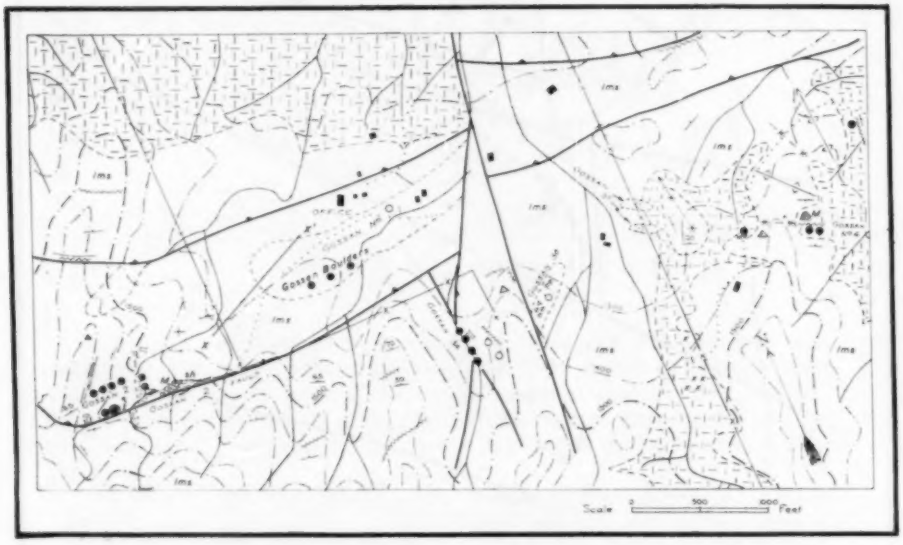


FIG. 3. Geology of the Carlota area (for legend see Fig. 3B).

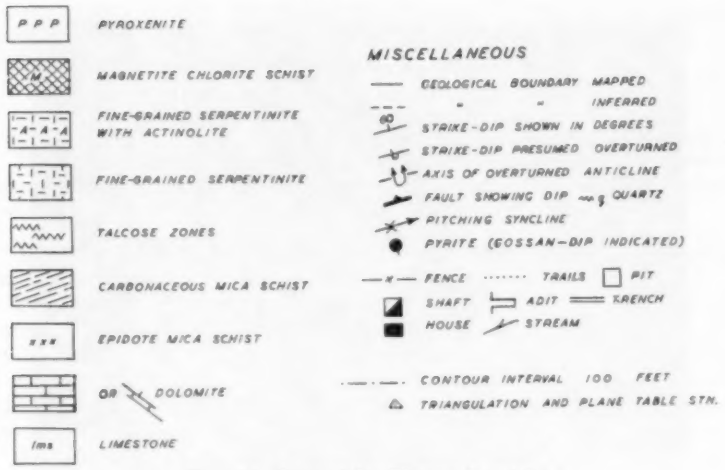


FIG. 3A. Legend for Figures 2 and 3.

GENERAL GEOLOGY

The Trinidad Mountains consist of isoclinally folded limestones and schists, which in the Carlota area, dip steeply northwards. The rocks are dynamically metamorphosed, devoid of fossils, and extremely lenticulated. Cleavage is absent and jointing is poorly developed.

The age of the limestones and schists is unknown. The rocks are older than dioritic intrusions on the north and Cretaceous sediments on the west. Thiadens (90) regards them as "at least of pre-Middle Cretaceous age."

Within the mountains, igneous rocks are represented by (i) nodular serpentinites derived from olivine bearing rocks, (ii) schistose serpentinites derived from gabbros and microgabbros, (iii) olivine-pyroxenite. Both types of serpentinite lack contact metamorphism. The pyroxenite is restricted to one locality (Fig. 2) and appears to have caused contact metamorphism of the surrounding limestone.

The schistose serpentinites—"greenstones"—are thought to be earlier than the nodular type. They have been strike-faulted into many sill-like bodies.

Pyrite deposits, as indicated by surface gossans and drill core samples, are in limestone adjacent to greenstone. Mineralization occurs in two main areas, chiefly within the Carlota and Victoria concessions (Figs. 2, 3). To date the Carlota has been the more important.

As no fresh ore is exposed at the surface, the orebodies are known and are referred to, by the numbers of their gossans. The numbers are those inherited by Wilson (98) from earlier reports. The numbering is in a measure objectionable for it gives a false idea of continuity. Several discontinuous bodies revealed by scattered gossan croppings are numbered Gossan 3, implying that the one orebody is several thousand feet long. However field mapping

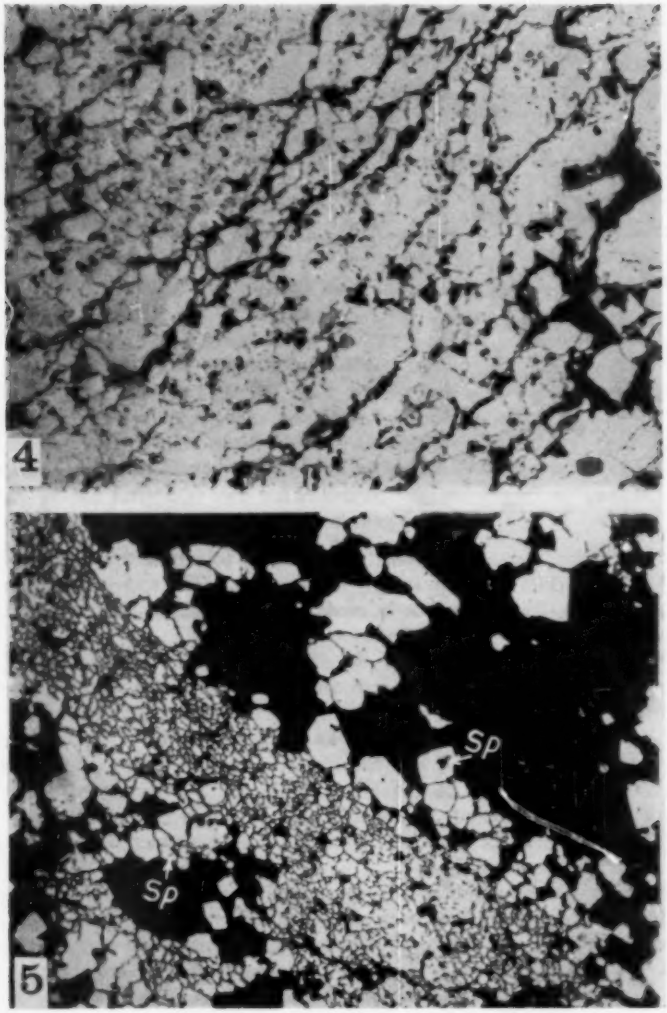


FIG. 4. Pyrite speckled with sphalerite showing banding from upper right to lower left. From core sample, Gossan 5, Drillhole 7B. (× 75.)

FIG. 5. Banded ore composed of large "clean" euhedral crystals and granular, less well-crystallized "dusty" pyrite. Rare specks of sphalerite are present (Sp). Sample from surface beneath route of old aerial tramway. (× 55.)

and the drilling of 1951–52 showed that "Gossan 3" comprises at least four separate gossans and that the simplified view of unbroken and continuous orebodies striking east–west needs modifying.

MACROSCOPIC DESCRIPTION OF THE ORES

The gangue associated with the pyrite is always of carbonate nature and may consist of schistose or foliated limestone, white calcite, or, less commonly, brecciated dolomite. The ore is of three varieties.

1) Massive or finely crystalline, containing from 50 to 100 percent pyrite, and in many places preserving the schistosity of the country rock (Fig. 4).

2) Protore, in which the percentage of gangue is greater. Generally protore is marginal to the massive variety but it may occur alone. Banding similar and parallel to that of the country rock is extremely well-developed. Crystal outlines are clear, most of the pyrite adjacent to gangue showing good euhedral faces. The upper and lower limits of protore are difficult to define but consist of some 20 to 50 percent of pyrite (Fig. 5).

3) Disseminated pyrite crystals, commonly euhedral, scattered along graphitic folia. Pyrite of this variety is generally marginal to protore or associated with it, but may occur alone. The upper limit is put at between 15 and 20 percent which is also the approximate division used by Locke (59) between aggregate and disseminated ore.

The pyrite, when well crystallized, consists of striated cubes. No other crystal form is macroscopically visible. The size of the cubes reaches a maximum of 3 mm in drill cores but larger crystals—up to 10 mm long—are represented by goethite pseudomorphs in surface croppings.

MICROSCOPIC STUDY OF THE ORES

Study of polished opaque sections, from orebodies presumably connected with Gossans 1, 3 and 5 (Figs. 2, 3), confirms the macroscopic examination. Pyrite is clearly the chief ore mineral but is veined by chalcopyrite in many places. The pyrite is of two types; one is finely crystalline and dusty with inclusions of countryrock; the other is cleaner, coarser, surrounds the dusty type and is more generally euhedral. Banding is better developed in protore than in massive ore. Although present in massive ore, the cleaner type pyrite shows up particularly well in the banded protores. The gangue is predominantly calcite with a few rhombs of dolomite. Most of these features are shown in Figures 4 to 10.

Sphalerite is locally present, either associated with chalcopyrite or as specks in massive pyrite. Galena, although suspected from chemical analysis, could not be identified with certainty.

Study of forty-eight thin sections supports data obtained from the opaque sections in that ore banding is conspicuous, and that pyrite is associated with calcite gangue in bands that closely follow the contortions of the adjacent rock. In addition, especially in well-banded protore near serpentinite, thin sections

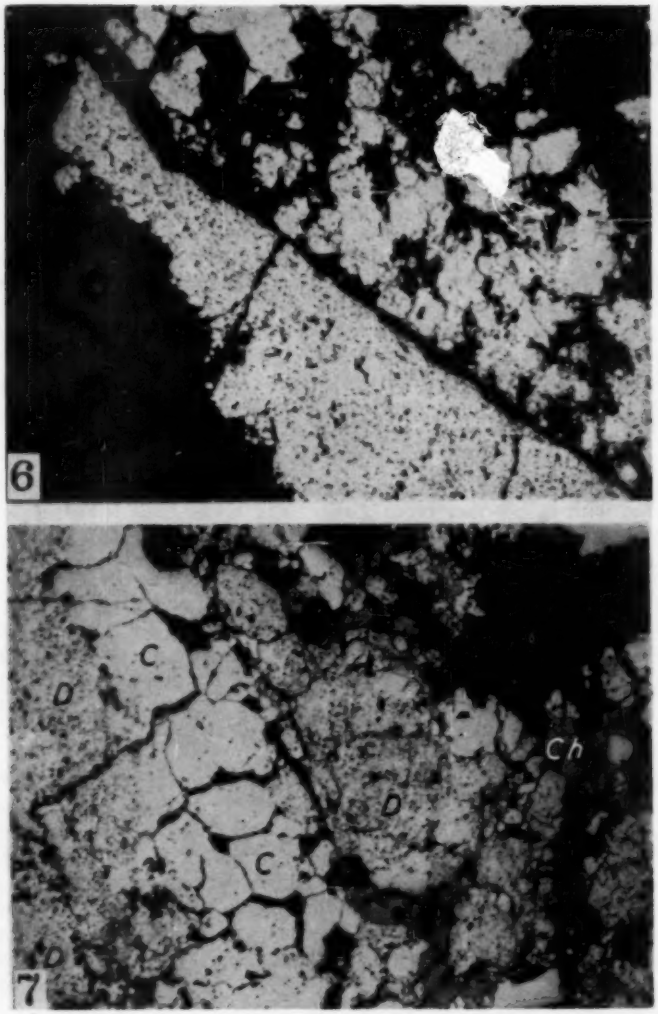


FIG. 6. Microfault cutting ore parallel to banding. With the exception of a few "clean" euhedral crystals, the pyrite is mostly anhedral and "dusty" with inclusions of country-rock. The gangue is calcite. Core samples from Gossan 5, drillhole 7A. (× 45.)

FIG. 7. Band of "clean" subhedral pyrite (C) margined by earlier (?), ill-defined grains of "dusty" pyrite (D), both fractured and veined by chalcopyrite (Ch). Occasional minute flecks of sphalerite present in the section. From core sample, Gossan 3, Drillhole 6. (×55.)

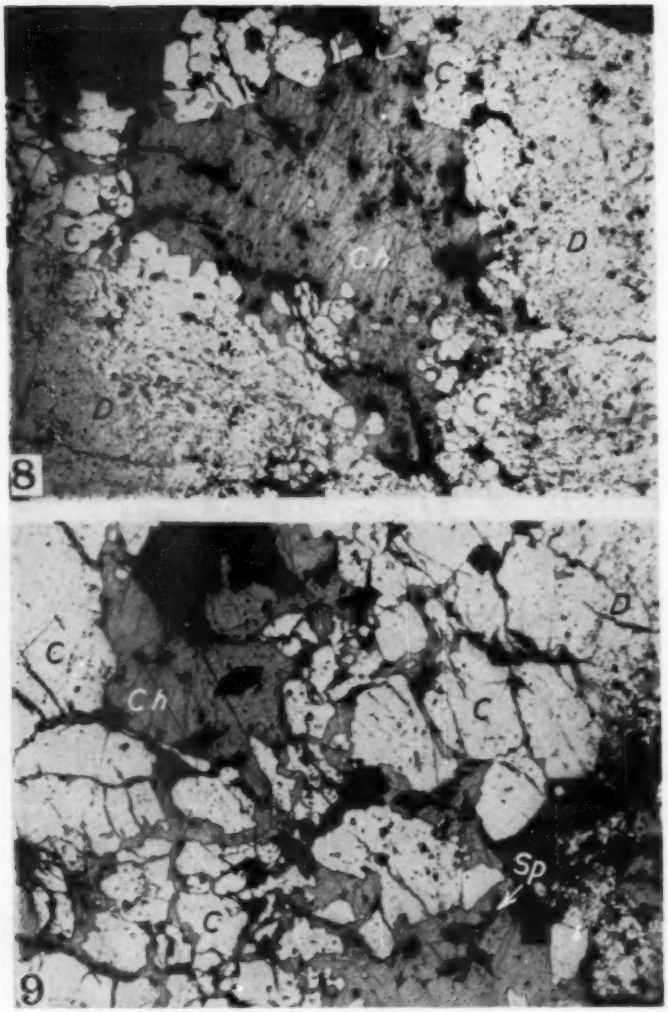


FIG. 8. Chalcopyrite (Ch) filling and replacing (?) pyrite. "Clean" euhedral to subhedral pyrite separates chalcopyrite from the more irregular and "dusty" type pyrite (D). Core sample from Gossan 3, Drillhole 10. (× 45.)

FIG. 9. Chalcopyrite (Ch) infiltrating fractured pyrite which is predominantly of the clean type; sphalerite (Sp). Core sample from Gossan 5, Drillhole 7A. (× 75.)

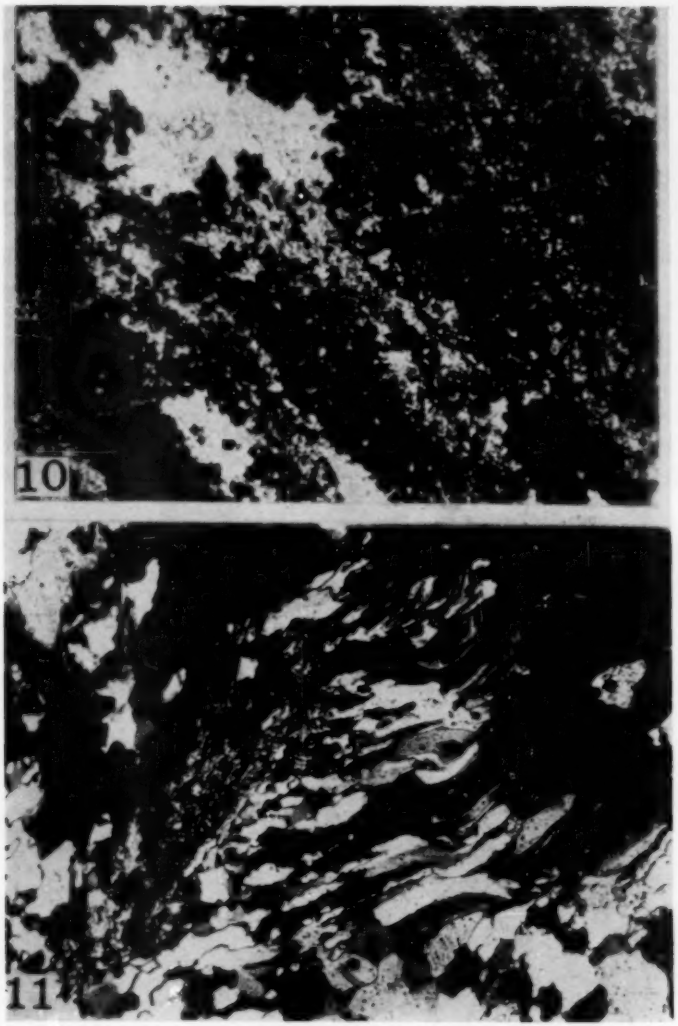


FIG. 10. Polarized light. Pyrite (black), showing euhedral outlines and association with calcite. Note banding from upper left to lower right. Core sample from Gossan 3, Drillhole 6. (× 25.)

FIG. 11. Polarized light. Sinuous streamers of quartz (with pressure shadows) radiating off pyrite. Note the minute colorless inclusions in the quartz. Marginal ore near greenstone, from core sample, Gossan 5, Drillhole 8. (× 60.)

reveal many hitherto unsuspected minerals associated with the pyrite. The following selected descriptions are typical of the cores obtained in drilling.

Gossan 5, Drillhole 8, Slide 12.—The rock consists of banded laminae of quartz, calcite, pyrite and sericite. The quartz, under crossed nicols, shows both mosaic structure and flamboyant streamers. The latter radiate from the corners and edges of pyrite cubes (Fig. 11). The calcite occurs as patches and rhombs, locally separated from the quartz by micro-shears lined with sericite.

The pyrite forms euhedral cubes in some cases bounded by sericite. With the exception of the sericite, it appears to have formed after the other minerals.

The sericite is wispy and shredded, with a faint pleochroism from a peculiar luminous blue-green to yellow-green. It was apparently the last mineral to form and occupies shears parallel to, and curving across, the schistosity.

In places, thicker vein aggregates of sericite contain residuals of a brown, isotropic, translucent mineral believed to be either picotite or perovskite. No sample large enough for X-ray could be found, so that determination of its composition was not possible.

The order of formation appears to have been: 1) mosaic quartz and calcite, 2) flamboyant quartz, pyrite and sericite.

Gossan 5, Drillhole 8, Slide 11.—The rock consists of plagioclase and sphene in a felted groundmass of prochlorite, together with quartz, calcite, minor amounts of pyrite, and other less common minerals.

The plagioclase forms clear round or irregular phenocrysts and appears to be earlier than the chlorite and talc of the groundmass. It shows cleavage and simple twinning and is optically positive with $2V$ = approximately 75°. Some crystals are almost euhedral; others consists of slices of plagioclase around a central core of plagioclase. The porphyroblasts contain a few inclusions of colorless, subangular, detrital quartz (?) and euhedral apatite. Refractive index determinations could not be made of the plagioclase which, however, is believed to be albite, which is ubiquitous in the district.

The prochlorite is a faintly pleochroic faded green with sporadic laths and laminae of sericite and possibly talc. Some of the prochlorite tufts have their cleavage at high angles to the overall schistosity.

Sphene occurs fairly plentifully as large and small granules both in the plagioclase and in the groundmass. The granules in the plagioclase may be slightly earlier than those of the groundmass. The latter are commonly faulted, broken, and strung along the rock laminae.

Calcite forms irregular patches and lenticles. Quartz appears as flamboyant streamers at right-angles to rock laminae. Sericite is rare, shows faint greenish pleochroism, and generally occurs between sheared portions of plagioclase. Epidote or lawsonite occurs as small scattered angular grains.

The pyrite, in some cases associated with sphene, is mostly confined to the groundmass as single or clotted euhedral crystals strung along the schistosity.

The formation of the minerals may have been simultaneous. The available evidence suggests, however, that the constituents formed in approximately the order: 1) sphene and plagioclase, 2) chlorite and calcite, 3) flamboyant quartz, pyrite, sheared and fractured or recrystallized sphene, and sericite.

Gossan 3, Drillhole 6, Slide 2.—The rock of this section (Fig. 12) is a chlorite–actinolite schist. The two major components are generally well separated with talc (and sericite ?) and pyrite along their junctions.

The chlorite is prochlorite in tufts or looped veinlets or rosettes. The actinolite forms long laths that may be wedged together or bent.

Quartz, apatite, zircon, sphene, pyrite and rutile (?) compose the remainder of the section. The quartz occurs in angular grains showing slight strain shadows. In places, one side of the quartz is sheared and margined by talc. Apatite and zircon are rare and occur in chlorite areas as irregular grains. The sphene forms rare wedge-shaped crystals in the prochlorite.

FIG. 12. Actinolite schist containing bladed actinolite, prochlorite (light grey), and euhedral-subhedral pyrite (black) associated with quartz (white). Locality: Gossan 3, Drillhole 6. (× 25.)

Pyrite appears to have been the last mineral to develop. It occurs as scattered euhedral grains in the chlorite areas, or between actinolite laths, or between broken fragments of quartz. Yellow rutile forms occasional inclusions in the pyrite.

The suggested order of formation for the constituents of the slide is: 1) quartz and actinolite, 2) chlorite and sphene, 3) rutile and pyrite. Reaction between pyrite and sphene may have produced the rutile.

NATURE OF THE ORE AND GANGUE MINERALS

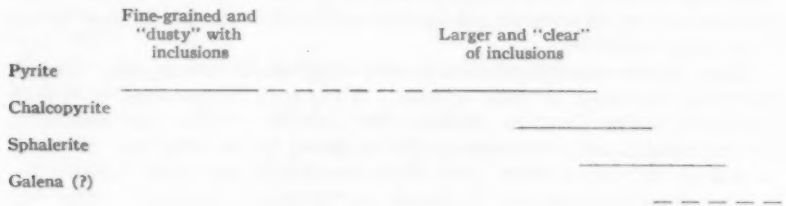
Paragenesis

The information obtained from thin sections shows that the introduction of gangue and pyrite was in approximately the following order: 1) sphene, pico-

tite; 2) actinolite, albite; 3) quartz, calcite, chlorite; 4) anomalous quartz, rutile, pyrite, sericite.

Phase 1) above, may represent magmatic or contact metaporphic minerals. Phase 2) is thought to represent dynamic metamorphism preceding or contemporaneous with pyritization. Phase 3) immediately preceded pyritization while phase 4) accompanied it. In general therefore gangue preceded sulfides.

The paragenesis of the sulfides, as obtained from polished sections, is shown below. The order is approximately the same as that outlined by Kania (51). The two phases of pyrite suggest that deposition of pyrite was spread over a longer period than that of the chalcopyrite or sphalerite.



It is not possible to compare the mineral succession at Carlota with that of every other pyrite locality. However a few selected examples can be considered where: gangue was introduced before sulfides, as at Carlota; gangue and sulfides were introduced together; sulfides preceded gangue.

In many deposits, gangue preceded sulfides. At Eustis, Quebec (35), quartz, sericite and carbonates were introduced before pyrite, whereas sphalerite followed. A similar sequence is reported from Jerome, Arizona (57). In the Philippines (48), sericite and silica preceded "solutions charged with sulfur and iron."

Overlapping between gangue and sulfides is reported from Flin Flon and Mandy (35). Generally here, arsenopyrite and dolomite preceded pyrite, followed in order by sphalerite, chalcopyrite, galena and calcite.

The introduction of sulfide before gangue is reported from Rio Tinto (97). This sequence is uncommon, and together with the ages of the two types of pyrite occurring at Rio Tinto is in direct contrast to Carlota (see: *Nature of the Pyrite*).

The differences between the two deposits might lie in their different tectonic and metamorphic histories. The Carlota ore was introduced contemporaneously with dynamic metamorphism (see: *Synopsis of Mineralization*) whereas, according to Finlayson (26), introduction of ore at Rio Tinto was the last event in a series of igneous and dynamic disturbances.

The significance of the calcite, chlorite, sericite and silica is debatable as these minerals are ubiquitous and occur in many mineral deposits. The calcite may be derived from the limestone countryrock. The chloritization can be explained in no other way than that of Prucha (70) and Smyth (86): "It appears to be the result of unusually potent chemical agents associated with the formation of pyrite."

A possible connection between the amounts of copper, sericite, and silica in ore deposits, is suggested by Mr. M. H. Gidel of the Anaconda Copper Mining Company (62).

At Carlota however, not enough samples are available to check the possible relationship. Although sericite appears to occur only in minor amounts, future work might show that the orebody underlying Gossan 5,[1] which apparently contains the most copper (Fig. 9), also contains the most sericite and silica.

The composition of sericite suggests a derivation from K-rich solutions from "alkali" siliceous magmas. The silicification, common at many pyrite localities, leads Kania (51) to a similar conclusion: "The great majority of these deposits, can be genetically connected with siliceous magmas (e.g., granites, acid porphyries, etc.) hence the extensive initial silicification barren of the metal sulphides."

To connect extensive sericitization and silicification with adjacent siliceous granites is convenient in many localities. Many such "connections" have been postulated in the Canadian Shield. The scarcity of silica and sericite at Carlota could equally conveniently be explained by invoking the low silica content of the serpentinites. But field association need only indicate the environment of deposition. It proves no "genetic connection." The real source may lie deeper, as McLaughlin (62) concludes.

Anomalous Quartz

Quartz comparable in many respects to the streamer quartz occurring in thin sections from Carlota, is reported from many parts of the world (1, 6, 31, 46, 48, 53, 55, 97).[2] It is variously described as: comb, columnar, fringe, lamellar or flamboyant. "Streamer" is used for the Carlota variety because it is sinuous. "Flamboyant" should be reserved for quartz individuals, as opposed to aggregates, that show sweeping, shadowy radial extinction.

Comparing the anomalous quartz of Carlota with that of Rio Tinto, there is no evidence at Carlota that the rock lamina "was splayed apart by the crystallization force of the growing pyrite" (97), or that the quartz subsequently grew in the protected environment around the pyrite. Instead, thin sections indicate that the quartz and pyrite grew together in areas already opened by rock movement, and that, if anything, the beginning of crystallization of the quartz may have preceded slightly that of the pyrite.

Compared with Canadian examples, the Carlota quartz does not form columns at right-angles to pyrite faces. Instead, it forms sinuous streamers, lacks straight extinction, and suggests that, in contrast to Canadian varieties, it formed not after rotation of the pyrite but contemporaneously with rotation. Strain shadows in the individual streamers indicate crystallization under conditions of stress.

[1] Gossan 5 alone of the gossans of Minas Carlota contains azurite and malachite.

[2] A comprehensive review is given by: Barringer, A. R., 1954, A study of mineralization in the pyritic deposits of southern Spain and Portugal: Ph.D. thesis, London University, p. 69–73.

Nature of the Pyrite

The two types of pyrite revealed in polished sections may represent: (i) two generations of pyrite, (ii) one generation with two phases—an earlier dusty phase and a later clean phase, (iii) one generation with recrystallization and clearing of part of the pyrite due to flexing of the ore contemporaneous with, or after, mineralization.

Regarding (i) the absence of sharp contacts between dusty and clean pyrite argues against two distinct generations. Moreover clean pyrite does not appear to cross-cut dusty.

Explanation (ii) is the simplest. Furthermore, it suggests that introduction of pyrite during the initial fine-grained stage was largely by replacement along graphitic laminae. The later phase apparently had room to develop larger crystals.

Process (iii) is possible but its results would be difficult to distinguish from those of (ii).

The disturbance of the marginal ore (spiralling and microshearing of the pyrite) seen in polished section, could be used in support of either (ii) or (iii).

It is interesting to note that two generations of pyrite are similarly postulated for Rio Tinto.[3] Here however, unlike Carlota, finer-grained pyrite is later. Williams (97) writes: "In some of the massive ore, two generations of pyrite are clearly recognizable, the smaller grains of the second generation often corroding the comparatively large hypidiomorphic crystals of the first. The first generation is virtually unattended by primary copper sulfides, whilst the smaller pyrite grains of the second generation occur both in the low and high grade ores and are accompanied by primary chalcopyrite."

At Carlota, the chalcopyrite shows a similar relationship. It may occupy openings lined with clean (late) pyrite (Fig. 8) or it may infiltrate between clean broken pyrite (Fig. 9). Chalcopyrite also forms veinlets that cut across both dusty (early) and clean pyrite. Somewhat similar chalcopyrite veinlets that traverse pyrite both concordantly and disconcordantly, are described from the Kupferberg, Germany (47) and also from Spain and the Urals.

The presence of openings filled with chalcopyrite and the absence of any lineation between chalcopyrite and sphalerite, together with the large crystals of late pyrite, indicate, in the words of Hanson (35): "In the early stages (of the Mandy pyritic orebody), replacement was important and filling of open spaces of minor importance; in the latest stages, replacement was less pronounced, and open space filling was becoming predominant."

The Possible Significance of Pyrite Crystal Form

Statement of the Problem.—Presumably because of the ubiquitousness of pyrite, the possible significance of its different crystal forms has not generally

[3] Barringer (*see footnote 2*) records: i) pyrite spherulites of metasomatic origin, ii) crystalline pyrite, iii) colloform pyrite, iv) crystalline pyrite. Colloform pyrite appears to have been the latest pyrite stage recorded by: Harris, J. F., 1956, The Kinousa pyrite deposit, Cyprus: B.Sc. (Hons.) thesis, Royal School of Mines, London.

been discussed. This is understandable, as pyrite references number several hundreds.

The present discussion is the result of a search of some 120 economic reports and papers. Only the most pertinent are quoted. The search, in many respects, was disappointing. Several writers mention pyrite as being "euhedral," "idiomorphic," "well crystallized" or "well formed" but only one in six gives the actual crystal form.

When this review began, it was not expected that any simple or exact relationship would be found. Instead it was hoped that some permissible generalizations might be obtained concerning the formation and association of the different forms of pyrite. As the approach was not an experimental one, the only data given on temperature and pressure of formation are those that may be read from the chemical environment of the pyrite or the associated minerals.

The Influence of Composition.—The influence of crystal form on the minor elements contained in pyrite is outlined by Auger (5).

> It is known that impurities are absorbed selectively by the various faces of a crystal. It is therefore possible that when a crystal assumes a different habit, the impurities that are generally absorbed by the predominant faces of this habit should be present in larger quantities. In the present case, nearly all of the samples had the cubic form. Only four were found to possess the octahedral habit. These four specimens had only one thing in common—a very low content of manganese. It so happens that these specimens are from the mesothermal type of deposits and as will be shown below, this low content of manganese is to be expected.

The point raised by Auger can be reversed: that is, the minor elements in the original liquid might influence the form adopted by pyrite. In other words, the composition of the original solution may influence pyrite form.

That this is so, is suggested by the list of noted pyrite localities in Dana (68). Different forms of pyrite, predominant in different areas, have different mineral associates.

The influence of the original solution, and perhaps also the temperature of formation, is indicated by the following observations from the Tintic district by Dr. T. S. Lovering (1957—personal communication):

> We found that the cubic form of pyrite was an early type unrelated to ore, but quite common in altered rocks thousands of feet from ore deposits, or on the other hand, in the altered rock adjacent to veins.
>
> The octahedral pyrite was most common in areas of strong argillic alteration, and we frequently found octahedral pyrite in veinlets of dickite or of alunite, quartz and zunyite. As the intense argillic alteration was most common in the outer zone of hydrothermal conduits carrying sulfide ore, we regarded the octahedral pyrite as a much more favorable indication than the cubic pyrite. It was not uncommon to find fissures coated with octahedral pyrite and this in turn coated with sulfides of a later stage.
>
> Pyritohedral pyrite was invariably associated with ore stage mineralization. In some fifteen years of experience in this district we have yet to find pyritohedral pyrite in any other association.
>
> A rare form of pyrite, the half form of the pyritohedron, which is illustrated in the new Dana, was found in altered limestone to a depth of 180 feet beneath ore stage

mineralization in somewhat recrystallized limestone. This material came out of a drill hole and although this peculiar pseudo-rhombic pyrite has not been recognized in other localities in the Tinto district, at least the occurrence is worthy of note. In this particular hole we had cubic pyrite in the upper part and then with depth, perhaps 100 feet above the ore, we found octahedral pyrite and then pyritohedral pyrite associated with small amounts of sphalerite. The pyritohedral pyrite was, of course, most abundant at the ore horizon itself, but beneath it we found only the half form of the pyritohedron—no cubes, no octahedrons, no pyritohedrons.

The problem is considered in a slightly different way by Ivanov (49) who believes that in the middle Urals, pyritohedrons are the primary forms of pyrite whereas cubic forms probably are related to metamorphic processes.[4]

The Influence of Associated Minerals.—Some tentative relationships were revealed when the crystal forms of pyrite were considered in relation to (A) a sedimentary environment, (B) carbonate gangue, (C) anomalous quartz, (D) other metallic sulphides.

(A) From photographs given by Schouten (79), it is apparent that many pyrite spheres of sedimentary origin, are composed not of radiating pyrite but of aggregates of minute cubes. In addition, Kania (51) has shown that when crystallized at low temperatures from artificial solutions, pyrite forms cubes.

(B) The association of pyrite with ankerite is mentioned by Charleworth (19). Ankerite with pyrite is also mentioned by Keys (53). Unfortunately neither author gives information on the form of the pyrite. It is believed, however, that they are cubes.

(C) The association of pyrite with fringe, lamellar or columnar quartz (see: *Anomalous Quartz*) is mentioned by: Bain (6), Graton et alia (31), Williams (97), Hurst (46) and Keys (53). Careful study of the photographs and descriptions that are given would indicate that where crystal form can be recognized, the pyrite occurs as cubes.

(D) Information on crystal form when pyrite is associated with other sulfides, is scattered through many Canadian papers notably that of Hanson (35). At Flin Flon, although the ore is very "fine-grained," photographs show pyrite cubes. At Mandy, pyrite occurs as cubes and as "rounded" and irregular forms. At Northpines, small druses contain cubes and pyritohedrons. Unfortunately no mention exists whether the two forms grew simultaneously or whether one preceded the other. At Eustis, pyrite occurs as cubes, pyritohedrons and "polygonal" grains.

The four deposits are alike inasmuch as gangue and ore indicate that all four orebodies formed at high to medium temperatures. However, the Flin Flon deposit, has apparently suffered the least post-ore deformation. And perhaps significantly, it is the only one, for which no pyritohedrons or "rounded" pyrite are reported.

To sum up, the following general conclusions[5] may be reached. 1) The cube is the most common form of pyrite. 2) The cube form is dominant in veins containing sericite, chlorite and carbonate, especially where the carbonate

[4] Harris (*see footnote 3*) reports pyritohedra at Kinousa and cubes at Limni but attempts no explanation.

[5] Since this was written a somewhat different summation has appeared: Sunagawa, I., 1957, Variation in crystal habit of pyrite: Geol. Survey of Japan, Rept. 175, p. 37–38.

is ankerite or where sulfides are scarce. 3) The cube is the form generally associated with anomalous fringing quartz. 4) The pyritohedron appears to develop at higher temperatures than the cube. 5) The pyritohedron may exist together with the cube where pyrite occurs with other sulfides, especially if these sulfides have suffered disturbance. 6) Octahedrons when present in mesothermal deposits may have a low manganese content.

The rounded forms of pyrite are not considered here. They may represent either oscillatory growth between cube and pyritohedron faces or replacement of pyrite by other sulfides.

Crystal Form at Carlota.—Not all the above conclusions could be confirmed at Carlota. No crystals could be distinguished in the fine-grained dusty pyrite. However all the euhedral crystals found in anomalous quartz or in sericite-quartz-calcite gangue, were cubes.

Macroscopic examination of the large clear pyrite reveals minute cubes. Microscopic sections show in addition cubes modified by possible octahedral faces (Figs. 5, 8).

The recognition of 3-dimensional crystal faces using a haphazard 2-dimensional plane is difficult. Nevertheless, if these extra faces are granted, most seem to occur in one zone only; for where one diagonal of a cube ends in an octahedral face, the other does not.

The connection between octahedral faces and manganese content cannot be proved at Carlota. The pyrite is fine-grained; separation of crystals would be difficult, and; contamination by manganiferous epidote and piedmontite would have to be avoided.

CHEMICAL ANALYSES

Experimental Procedure

Chemical analyses made in 1913, 1917 and 1952 are given in Table 2. As can be seen the ores are practically free from arsenic, lead and phosphorus. Samples A and B are 10 percent higher than drill core averages for, according to Holden (43), good grade ore is crumbly and does not core as easily as the more siliceous pyritic ore of lower grade. However, in the samples taken in 1917 no such discrepancy between mine and core analyses was reported.

Using the complete sets of analyses from former reports an attempt was made to see if any relationship existed between certain elements. Sulfur-phosphorus, iron-phosphorus and gold-copper were studied as these elements are not so affected by vagaries of sampling nor the presence of variable amounts of gangue.

Interpretation

The results plotted in Figures 13, 14, and 15 show (i) that the phosphorus content, at least when iron is between 42 and 47 percent, is highly variable; (ii) that the phosphorus content, at least when sulfur is between 46 and 53 percent, is highly variable; and (iii) that in general the higher copper contents accompany low gold contents.

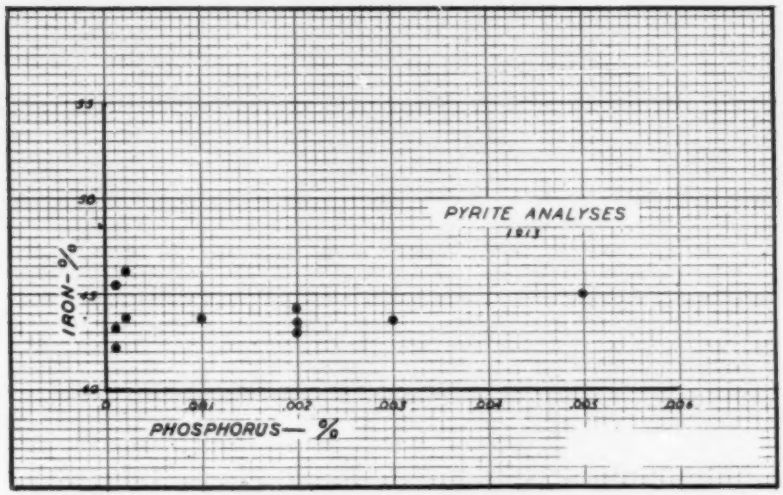


FIG. 13. Analyses of iron v. phosphorus.

TABLE 1

CHEMICAL ANALYSES OF PYRITIC ORE

	A	B	C	D	E	F	G
Fe	43.74	45.41	38.88	39.70	35.34	37.58	31.62
Cu	1.337	0.16	0.65	0.74	0.48	0.63	1.34
Pb	x	x	x	x	0.0007	0.231	0.025
Zn	x	x	x	0.84	1.02	1.56	1.18
As	Nil	x	x	Tr	0.001	0.030	0.017
Ni	x	x	x	x	x	Nil	Nil
Co	x	x	x	x	x	0.030	0.076
P	0.0011	x	x	0.017	0.0098	x	x
S	50.51	51.12	39.45	36.57	39.71	41.80	34.40
CaO	x	x	x	4.74	5.95	x	x
MgO	x	x	x	3.17	3.07	x	x
Al_2O_3	x	x	x	3.24	2.10	x	x
SiO_2	x	x	x	0.74	x	0.15	9.85
Se & Te	x	x	x	x	x	0.002	0.002
Insol	0.925	x	x	x	0.37	x	x

A—average of 11 samples from 46 feet of the 160 foot level at the bottom of the Phoenix Shaft (Holden, 1913).

B—grab sample from mined material (Holden, 1913).

C—average from drill core analyses (Holden, 1913).

D—grab sample from New (No. 2) Shaft on the 250 foot cross-cut (Yeatman and Berry, 1917).

E—channel sample by Norman Keller on the 250 foot cross-cut starting 5 feet from the hanging wall to within 10 feet of the footwall and representing 60 feet of pyrite (Yeatman and Berry, 1917).

F—average of 6 samples from Drillhole 10, Gossan 3 (Freeport Sulphur Co., 1952). Ni present was less than 0.003 percent; Fe, Cu, and S not actually determined but derived from arithmetical averages of previous determinations.

G—average of 2 samples from Drillhole 7, Gossan 4 (Freeport Sulphur Co., 1952). Ni, Fe, Cu, S, determinations, as in F, above.

The relationship between high copper and low gold values can be explained if the gold is contained in the pyrite. Thus the more chalcopyrite present in a sample, the less pyrite and the lower the gold content.

The association of gold with pyrite is well known. Schwartz (80, p. 385) in a comprehensive study of the host minerals of native gold, found "gold described as in contact with pyrite in 48 out of 115 deposits reviewed."

No information is available on how this gold is contained in the pyrite. Auger (5) in studies of Canadian pyrite, found that gold generally was a late mechanical introduction. If this is the case at Carlota, the finer-grained (early) pyrite may, because of greater surface area, have higher gold values than the larger (later) pyrite. A similar phenomenon is reported from Kerr Addison, Ontario by Hawley (36, p. 277). (A)

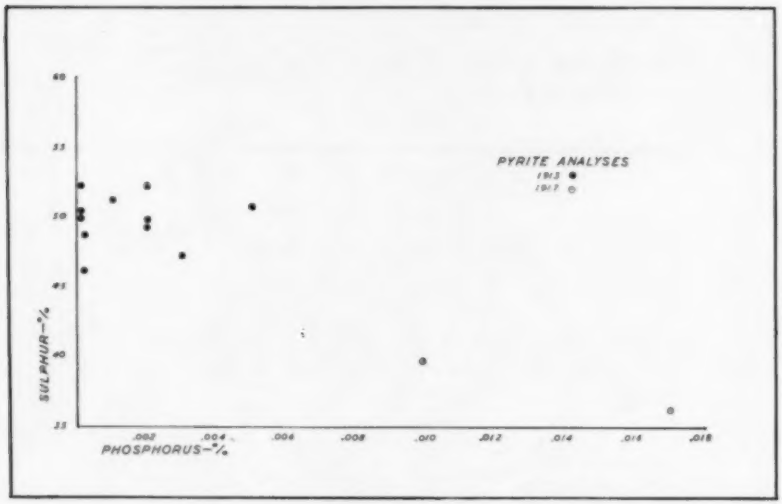


FIG. 14. Analyses of sulfur v. phosphorus.

On the other hand Haycock (37) points out the tendency for "very finely divided and sub-microscopic gold" to be contemporaneous with deposition of the host mineral. Coleman (20) reaches essentially the same conclusion.

That the grain size of pyrite may also be related to the minor elements contained within the crystal structure is shown by Hawley (36) in spectrographic studies of four Canadian mining camps. Specimens from the Porcupine district were studied in more detail than those from other districts (p. 297): "Variation in grain size of pyrite in single specimens shows considerable variation in minor element content, cobalt and nickel being lower in the coarse and higher in finer sizes, while the reverse is true for titanium and arsenic." (B)

So far attempts have been made here to relate minor elements to the

crystal size. Whether the reasoning can be carried a stage further to see if the minor elements can be related to temperature of formation is doubtful. For on the one hand, referring to Kerr Addison, Hawley (36, p. 276) writes: "No outstanding differences in composition of pyrite appears related to different temperature readings."

On the other hand, in speaking of Porcupine (p. 298): "Variations in composition studied in relation to temperature recordings made by F. G. Smith, by electrical and decrepitation methods, indicate that in general pyrite giving only high temperature recordings contains less gold, silver, arsenic, lead and

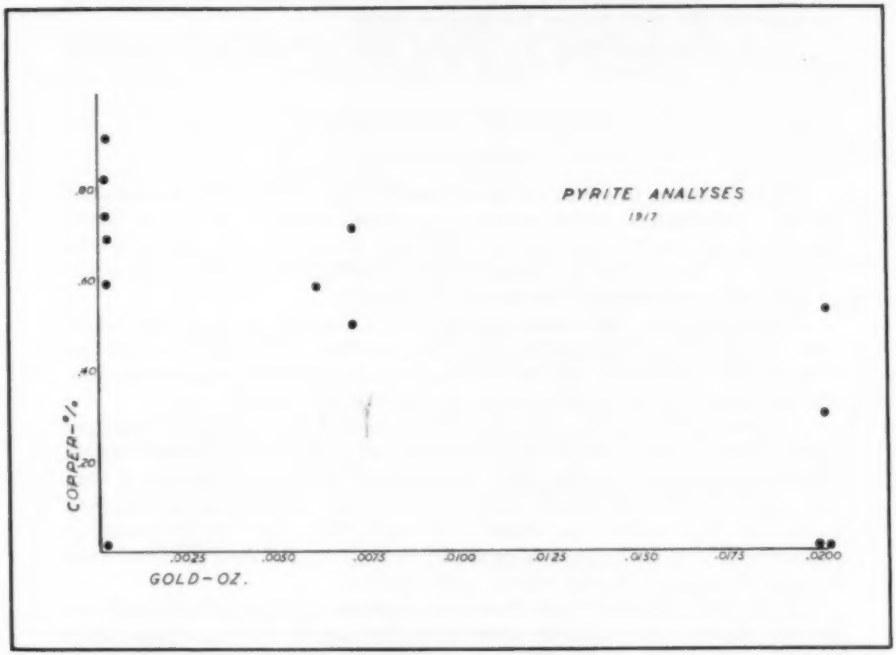


FIG. 15. Analyses of copper v. gold.

zinc but more cobalt, nickel and, in some veins, tin than that giving only low temperature readings." (C)

Confining our attention to the Porcupine mine alone, it is difficult to reconcile these statements. If statements (A) and (B) are combined, large-grain pyrite (presumably large crystals) is lower in cobalt and nickel, whereas small grains (presumably also small crystals) are higher in cobalt and nickel and have higher gold values.

Statement (C) appears to contradict this: for "less" gold is now reported associated with "more" cobalt and nickel. No mention is made whether

at Porcupine, large grains are equivalent to pyrite of higher or lower temperatures.

The applicability of these findings for Carlota may be summed up as follows: 1) High gold—low copper values indicate that gold at Carlota is contained in pyrite and not in chalcopyrite. 2) If gold is a mechanical introduction—which is likely—it may be concentrated in the fine-grained pyrite. 3) Although the fine-grained pyrite is early and presumably formed at a higher temperature than the "clean" pyrite, no direct relationship is believed to exist between the temperature of pyrite formation and gold values. 4) Allowing for differences in interpreting published data, cobalt and nickel values may be higher in the early formed fine-grained pyrite.

The possible significance of cobalt and nickel in regard to the genesis of the ore is discussed under *A Possible Syngenetic Origin*.

THE NATURE OF THE OREBODY

General Remarks

Any discussion of pyrite ore is difficult because of the ubiquitousness of pyrite. As expected, pyrite references are multitudinous. Few were found specific to the problem of Carlota. The best known classification of pyrite deposits, to date, is that of Lindgren (58) based on temperature and depth of formation as determined by mineral association.

Notwithstanding difficulties mentioned by Lindgren, an up-to-date world wide compendium of pyrite deposits is long overdue. This should set out not only mineral composition but also: the geological association, paragenesis, age, possible source, tectonic environment and geotectonic control.

At present, information on pyrite deposits is scattered under the headings: pyrite, copper, sulfur. Each category comprises deposits formed under many different conditions. At the 1926 International Geological Congress, a start was made toward a systematic description of pyrite deposits but no standard method of presentation was adopted. Consequently useful as the resulting publication is, its information is generally incomplete and does not lend itself to rapid comparison of one deposit with another.

To date the implications of metallogenic epochs and metallogenic provinces are well known (10). On the other hand, attempts to relate ore deposits to tectonic environment and geotectonic controls, are scanty. Among the more recent papers in English are those by Andrews (4), Loughlin (60), Umbgrove (92, 93) Kanehara (50), and Rade (72).

Temperature of Pyrite Formation

It was hoped that use of the pyrite "geothermometer" (84) would yield information on the temperature of formation of the Carlota pyrite.

The geothermometer is based on the principle that: (i) more perfect crystals form at higher temperatures than do less perfect ones, (ii) more perfect crystals have a thermo-electric potential that is more negative, whereas less perfect crystals have a thermo-electric potential that is more positive.

Although more perfect crystals have lower specific electrical resistance,

the measurement of this resistance "is a difficult operation, especially in the case of brittle crystals such as the opaque minerals."

However, there are objections to the thermo-electric potential method. Discontinuities within the crystal under examination may cause the temperature of deposition, obtained by this method, to be too high. In addition, some mineralogists feel that the calibration curve of Smith (84) is based upon insufficient data, and that not enough thermo-electric potential determinations have been made on pyrite crystals grown at known temperatures and pressures.

Nine polished sections and four thin sections were submitted to Professor F. G. Smith of Toronto University. His report reads as follows:

A large number of readings from each polished section were made and compiled in frequency-value curves. Most were of the simple error-curve type with a standard deviation of 20° C. Some are distinctly skew.

The results indicate several stages of formation of pyrite, one near 600°, one near 500°, one near 350° and one near 250°. Those specimens with coarse chalcopyrite give readings 433° to 495°. Tentatively, this might be taken to represent temperatures during chalcopyrite emplacement, during which the prior pyrite (readings near 600°) was partly or wholly recrystallized.

TABLE 2

PYRITE GEOTHERMOMETER DETERMINATIONS FOR CARLOTA ORES

Specimen	Estimated temperatures of formation
Orebody No. 1	630°, small skew to lower temperatures
Gossan 3A (1)	470°, 600°, long skew tail to low temperatures, in 200–300° range
Gossan 3A (2)	240°, 530°, 600°
Gossan 3A Drillhole 6	433°
Gossan 3A Drillhole 10 (1)	485°, 600°
Gossan 3A Drillhole 10 (2)	495°, small skew to higher temperatures
Gossan 5 Drillhole 7A	475°
Gossan 5 Drillhole 8	580°, small skew to lower temperatures

Tentative implications of these results (Table 1) are: 1) that the early dusty pyrite was introduced at 600°, 2) that the introduction of clear pyrite took place at 500° C followed by 3) chalcopyrite emplacement between 495° and 433° C. Those specimens that give the lowest readings, contain sphalerite and, as suggested by Smith, are those most likely to contain galena.

Decrepitation of the quartz associated with the pyrite was not attempted because liquid inclusions large enough to identify the contents were not found. In addition, although solid inclusions are abundant, many occur along healed cracks making it difficult to estimate what proportion are primary.

Direction of Mineralization

A review of the main methods of determining direction of flow of mineralizing solutions has recently been given by Gross (33). Textural methods for determining direction of replacement are outlined by Edwards (23).

The direction of flow of the original ore solutions at Carlota, could not be determined. If oriented drill cores could be obtained, it might be possible to reconstruct direction of flow from the relative positions of chalcopyrite and sphalerite. It is believed that at Carlota sphalerite formed later than chalcopyrite. The relationship between these two minerals has been discussed by Teas (89) who believes, however, that in general when the two occur together, chalcopyrite is the later mineral.

It is conceivable that the development of pyrite faces may be related to the direction of solution flow. Thus, the development of one zone of octahedral faces and suppression of the other (see: *The Influence of Associated Minerals*) may be related to the lineage structure and axis of growth (83) and this in turn to the direction of solution flow.

However, no stoss or "upflow" side (67) to crystals, or any significant relationship between gangue and ore (34), was seen in either macro or micro-section.

The Geological Association of the Ore

The geological association of the ores is considered here, both at depth and in the field. At depth, underground workings and drillholes show that the pyrite commonly occurs between greenstone and limestone.

In the field pyrite, at least as outlined by gossan (Figs. 2, 3), occurs in limestone at contacts with greenstone. However it is not certain if, in the words of Holden (45), pyrite always: "occurs between a hanging wall of schist or greenstone and a footwall of blue limestone. At Gossans 2 and 8, greenstone dips underneath limestone." At Gossan 6, the relationship appears reversed. Elsewhere it is unknown.

Mineralization is not apparently confined to any one type of limestone. Although dolomite may occur with brecciated protore, on the evidence available no correspondence exists between "magnesian metasomatism" and pyritization, as has been suggested in many places, notably lately for the Taro district of Japan (52).

The influence of faulting on localization of ore is noteworthy. Most limestone-greenstone contacts are also strike faults. Gossans 2 and 3A occupy tension areas opened by fault movement.

The relationship of serpentinization to mineralization is uncertain. That serpentinization is related to mineralization might be deduced from the almost complete serpentinization of greenstone of the ore areas.

However, the relationship may be more apparent than real. That serpentinization is only incipient on Honeymoon Hill [8] may be related not to the lack of mineralization there but to the large size of the intrusive. This would suggest that the water necessary for serpentinization was derived externally. Or, it might be argued, larger intrusives were better able to resist the stresses that preceded and prepared the way for serpentinization. Yet a third way of considering the problem would be to say that Honeymoon Hill is a later intrusion that was only affected by the end stages of serpentinization.

[8] About ½ mile southwest of Fig. 2.

Whatever the relationship at Carlota, there is no evidence that, as postulated for the Panay pyrite (76), serpentinization was accompanied by an increase in volume which: "Must have set up further stresses in the older formation, thus adequately preparing the stage mechanically for the invasion of ore-forming solutions."

On the contrary, thin sections and field work indicate no increase in volume on serpentinization. The lack of increase in volume is corroborated by Hess (40, p. 653) who argues for a slight 5 percent decrease in volume. The implications of such a decrease are considered elsewhere (see: *The Banding at Carlota*).

The Banding of Pyrite Ores

A Review and Classification.—Most pyrite deposits are aligned parallel to the geological grain of the region in which they occur. Consequently they possess a banded or schistose structure. In many cases, controversy exists whether this structure was inherited from the countryrock or was acquired by later metamorphism. Therefore, before any theory of ore genesis or introduction can be postulated, a correct interpretation of banding is necessary. To do this, deposits in other parts of the world will have to be considered briefly.

In this discussion, banded pyrite is the only type of ore considered. It includes ore that is foliated, schistose, platy, sheeted or laminated. Banded deposits may be divided into two classes—those of epigenetic origin and those originally of syngenetic origin.

The epigenetic deposits are divisible into three theoretical categories, according to whether banding (A) was inherited, (B) was formed by introduction of ore concurrently with deformation, or (C) was formed by post-ore deformation. The difficulty of interpreting banding is reflected in the number of writers who describe "schistose" pyrite but who do not discuss the implications of the schistosity.

The pre-ore or inherited banding of category (A) is usually difficult to discuss because the introduction of ore and the preservation of banding have to be considered together. Nevertheless the methods advocated extend from the "metasomatic replacement" of Stickney (88), through the "selective replacement" of Bruce (13) and Newhouse (66), to the "replacement" of Graton (30), Ross (75), Pek (69), Santos-Ynigo (76), and Zavaritsky et alia (102).

Where a colloidal texture is present in the pyrite, or where barite forms part of the gangue, "rhythmic precipitation" with or without replacement is postulated. This is advanced for the pyrite of southern Spain by Edge (22), Boydell (12), Williams (97), Allan (2) and Roso de Luna (74). The subject is also reviewed in part by Kania (51).

Category (B) is frequently difficult to separate from category (C). It includes the replacement and flowage ores described by Newhouse and Flaherty (65). It may also include some Carpathian ores (73), some Norwegian ones (27), one or more ores from the Urals (63), and the "mobilized" pyrite of Waldsassen, Germany (61).

Category (C) comprises deposits affected by post-ore deformation. It is an easier category to "use," than the other two because banding can be considered separately from the problem of ore introduction. In this category are the deposits of Slocan (91), Rammelsberg (56), Northpines (35), Norway (95), and the Urals (63, 101, 103). In general these deposits are pre-Cenozoic.

Banded ores, originally of syngenetic origin, include those of northern New York (70) and, according to Carstens (16, 17), some Norwegian deposits. The Rammelsberg ores of Germany are regarded by some authorities as syngenetic.

In common with the banded epigenetic ores, syngenetic ores are parallel to regional structure. The banding originally of sedimentary origin, has in most cases, been affected by one or more orogenic disturbances. The New York deposits are Precambrian; the Norwegian and German ones are Palaeozoic.

The Banding at Carlota.—An understanding of the banding at Carlota is necessary in determining the history and origin of the ore. Unfortunately the evidence is meagre. The orebodies cannot be studied underground, so that it is not known if they split into veinlets, or are wrapped around by the lamination of the countryrock, or simply merge into the countryrock. Thus, information which might indicate whether the ore banding was inherited or post-ore, is not available.

Consequently the evidence has to be read from the surface gossans. On the one hand, a careful inspection of the gossans failed to reveal any inclusions of countryrock, oriented or otherwise, which could be used to determine whether banding was pre-ore or post-ore. A similar technique was used underground at Slocan by Uglow (91).

On the other hand, the banding in the gossan shows that the banding of the ore is conformable with the lamination of the countryrock and with axes of the ore lenses. The intercalation of schistose gossan with laminae of limestone indicates that the ores are conformable and possibly of "replacement" origin.

Drill cores show that the banding in the ore is parallel to the regional lamination. The ore consists of alternate bands of fine and coarse pyrite, each a fraction of an inch thick. The coarse bands are more conspicuous and thicker than the fine.

As already mentioned, the fine pyrite is slightly earlier than the coarse. It preserves the laminated structure of the countryrock and is so riddled with inclusions that it is "dusty" in polished section.

The coarse pyrite on the other hand is a space filling. As it is merely a later phase of pyrite and not a separate generation, mineralization at Carlota must have been accompanied by either rock movement or chemical removal of limestone.

Movement and removal of limestone may, of course, have taken place together. The point here is that the location of gossans at flexures in limestone, together with the nature of the early and late pyrite, indicates simul-

taneous movement and mineralization. Thus, the Carlota deposits belong to category (B) of the classification outlined above.

At this stage, an analogy might be useful. The laminated limestone may be compared to a pack of cards lying on its side. The cards are first gently flexed, then opened by pressure applied at the ends. During the initial flexing, early pyrite was introduced largely by replacement along graphitic laminae. During the "opening up" stage, later pyrite and other sulfides were introduced as space fillings.

From experimental studies on metasomatism, Bain (7, p. 526) concludes that: "In a given crystalline limestone, the pore space is greater and the pores wider where the beds are highly deformed on anticlines and in synclines than when the beds are extremely regular."

An additional 5 percent space may also have become available at contacts with greenstone on the serpentinization of the original microgabbro (40). The well-developed banding of the gossan along these contacts shows that the space made available was not a simple cavity. Instead, it indicates that a reduction in volume of the adjacent greenstone may have caused a local relaxation of pressure enabling ore fluids to infiltrate along laminae and replace limestone.

From the foregoing remarks, it is apparent that although nothing is known of direction of mineralization, the mineralization was essentially along the lamination and, with the exception of a few late chalcopyrite stringers, was not at right angles. The folia, especially where graphitic, appear to have been an effective barrier to any transverse movement of ore fluid.

Deformation after mineralization appears to have affected only marginal ore, causing bent twin lamellae in calcite and disturbance of pyrite (Fig. 6). Somewhat similar deformation of pyrite ore is reported from the Milan Mine, New Hampshire (24). At Carlota, the post-ore deformation may represent a late differential adjustment of limestone around pyrite.

The only alternative explanation of the banding at Carlota is that the fine pyrite is a secondary feature caused by granulation and flowage. This is unacceptable because neither the coarse pyrite nor the chalcopyrite-sphalerite show evidence of flowage, or crystallization under directed pressure. Moreover, it conflicts with the results of pyrite "geothermometry."

ORIGIN OF THE ORE

The various features of mineralization have been discussed in detail so that this final section can be as concise as possible. It may have been obvious from some of the preceding remarks, that the pyrite is of epigenetic origin, but before discussing this further, a possible syngenetic and combined syngenetic-epigenetic origin will be considered.

A Possible Syngenetic Origin

Essentially this implies that the pyrite may be the same age as the enclosing sediments and is of sedimentary origin.

An original biochemical genesis with later concentration by metamorphism has been postulated for pyrite deposits in New York (70), Norway (15), Germany (38, 61, 77).

If the Carlota pyrite was originally syngenetic, the existence of pyritiferous horizons would be expected and it would also be likely that the serpentinites represent metasomatized sediments and not igneous rocks. However, no pyritiferous horizons were discovered. Pyrite occurs only in the proximity of limestone-serpentinite contacts.

With respect to the original nature of the serpentinite, thin sections show that an igneous rock has been serpentinized. Additional proof of the igneous origin, is provided by the minor-elements. The nickel content of the serpentinites varies from 0.04 to 0.5 percent (Table 3), which corresponds to the "Class A" serpentinites of Faust et alia (25). A similar relationship exists with respect to the chromium and cobalt content; the findings of Faust et alia (25) again show the Carlota greenstone to be of igneous origin.

TABLE 3

SEMI-QUANTITATIVE SPECTROGRAPHIC ANALYSES—IGNEOUS ROCKS

No.	Locality	Co	Cr	Ni	Nb(?)	B	Si	Mn	Mg	Fe	Al	V	Ca	Cu	Ag	Ti
1	La Guaos, nodular serpentinite	.01	.4	.5	.03	.004	10	.2	15	5	1	.01	.03	.007	.01	.03
2	Fine-grained serp., Wilson Ridge	.025	.13	.38												
3	Fine-grained serp., south of Goro	.007	.03	.04												
4	Lawsonite-Schist, Hungry gossan	.015	.02	.05												
5	Amphibolite, Deadhorse Ridge	.006	.01	.01												
6	Amphibolite, Point 1, main road	.006	.07	.06												
7	Sheared amphibolite from Point 9 on main road	.006	.08	.05												

Analyses by Department of Mines, Ottawa.

The minor elements in the pyrite itself can also be considered. Because Co, and Ni, are sufficiently closely related in atomic radius to iron, they may occur in pyrite. Carstens (16, 18) believes that sedimentary pyrites are characterized by the predominance of nickel over cobalt. On the other hand, both Auger (5, p. 407) and Hawley (36) have discovered anomalies in the postulated Co:Ni ratios. Assuming that Carstens' assumptions are correct, the slight evidence available from Carlota (Table 2, F and G) would indicate that the pyrite is not of sedimentary origin.

Summing up: on the basis of all the above arguments, the Carlota pyrite is not of sedimentary origin. This also is apparently confirmed by the high temperatures of formation recorded for the pyrite, though these could conceivably be related to later contact metamorphism.

Sulfur isotope determinations (54) of Carlota pyrite were inconclusive. Two determinations by the Lamont Geological Observatory on samples from beneath Gossans 3 and 5, gave S^{32}/S^{34} ratios of, respectively, 22.360 and 22.345, ± .01.

A Possible Syngenetic-Epigenetic Origin

A combined syngenetic-epigenetic origin implies that part of the pyrite was derived from the countryrock and part from hydrothermal or magmatic sources. For this, sulfur either native or in the form of anhydrite or gypsum, would have to be supplied from the limestones; and iron, presumably ferrous (82), from a magmatic source.

An origin of this type may be suspected at Grosseto, Italy (71) or at the Brittania Mine, Canada (78) where anhydrite or gypsum is present. However at Carlota, neither mineral was discovered near the pyrite. With respect to iron, magnetite is scattered throughout the serpentinites but none occurs in the ore.

Another type of syngenetic-epigenetic pyrite is that described by Hegemann (39) and Seifert et alia (81). These authors believe that certain concordant pyrite bodies are the metamorphosed product of both sedimentary and submarine magmatic activity.

The idea of submarine volcanic activity is of interest because of the geosynclinal nature of the Carlota limestones. However thin-sections of the serpentinites do not suggest that they represent altered lavas. Nor does pyrite apparently lie "underneath" greenstone (Fig. 2A) without invoking complicated structural movements. In addition, some orebodies do not lie along limestone-greenstone contacts but are strung along faults. Therefore, on the evidence available, the Carlota ores have not originated from submarine lavas.[6]

An Epigenetic Origin

A theory of epigenetic origin may encompass formation by gravity separation, contact metasomatism or hydrothermal magmatic solutions.

Gravity Separation.—A discussion whether sulfides crystallize early or late in the cooling history of a magma, is not intended. The various ideas on the subject are reviewed by Bateman (9). It is proposed here to consider only whether the pyrite could represent an early formed gravity-separated phase. Whether this consisted originally of crystals or an immiscible liquid is immaterial for present purposes.

Gravity separation from the original gabbro of the greenstone is ruled out, for the following reasons. 1) The pyrite is located in limestone, not greenstone. 2) No layering or other signs of differentiation are visible in the greenstone, either in the field or in thin-section. 3) No pyritic bodies of this type are described in the literature. 4) The same structural arguments apply that were used against the hypothetical origin of submarine lavas.

So far, only gravity settling from the greenstone with the subsequent tilting of both greenstone and ore, has been considered. Another possibility remains—whether the ore might not have been introduced into its present position from above, after tilting, and thus be independent of the greenstone.

[6] Notwithstanding the Carlota evidence, persuasive arguments for an "exhalative-sedimentary" origin of other pyrite deposits are advanced by: Oftedahl, C., 1958, A theory of exhalative-sedimentary ores: Geol. Fören. Stockholm, Förh. bd. 80, h. 1, no. 492, p. 1–19.

Although no outliers of the amphibolite-diorite complex (which occurs along the northern margin of the Trinidad Mountains) have been found within the mountains, no proof exists that the amphibolite-diorite might never have extended further south. Therefore the possibility has to be considered that these rocks at one time may have have lain unconformably on a surface bevelled across isoclinally folded limestone and greenstone.

Introduction of ore, in this case, would involve a gravity separation of sulfide, presumably liquid, with the subsequent draining off and injection of this liquid into underlying pockets between limestone and greenstone. Similar segregation and injection of sulfide has, at one time or another, been postulated for different sulfide bodies (9, 21).

As interesting as the hypothesis is, it is rejected on the following grounds: 1) It is not the simplest explanation; it introduces further problems involving tectonics, erosion, sedimentation and isostasy. 2) It involves injection downwards some 4,200 feet, the distance from the base of the amphibolite-diorite (projected above the orebodies), to the orebodies themselves. 3) It is uncertain whether many sulfide "segregations" have, in fact, formed by injection from above. Moreover injection of ore fluid is directed towards areas of lower pressure which logically should be upwards and not downwards.

Contact Metasomatism.—Contact metasomatism is distinguished from contact metamorphism by Barrell (8). With many mineral deposits, it is not possible to be so precise. Partly to resolve this difficulty Lindgren used the term pyrometasomatism but this tends to conceal the apparent contact nature of the Carlota deposits.

Contact metasomatism is used here, because pyrite has been added to the limestone. It has already been shown that neither the pyrite nor iron or sulfur have been derived from the countryrock.

The world-wide occurrence of deposits of banded pyrite along the margins of, or between, igneous rocks, would suggest that many have been formed by contact metasomatism. However, this is not so. Because of the difficulties of interpretation, most of these deposits are regarded as replacements. In the words of Bichan (11), replacement becomes: "The universal touchstone . . . wherever geologists have encountered baffling and inexplicable problems, they have fallen back countless times on this wonderfully inclusive term: replacement."

The problems are no less baffling and inexplicable at Carlota. On the one hand, the ore occurs in limestone at contacts with igneous rock; or if igneous rock is not always exposed, it is ubiquitous enough to be present below ground. The gangue also consists of actinolite, sphene, picotite, and epidote which are common contact minerals. Moreover, pyrite geothermometry indicates a high temperature of formation of 600° to 400° C, similar to that advocated by Lindgren (58) for pyrometasomatic deposits.

On the other hand, the minerals mentioned are not conclusively "contact." They can also develop by dynamic metamorphism or hydrothermal action and may even, as shown by Hickok (41, p. 249), be absent from many contact deposits. In addition, magnetite, ilmenite, pyrrhotite and the more typical skarn minerals, are lacking.

Another difficulty concerns the apparent lack of lateral relationship with the adjoining igneous rock. An actinolitic "barrier" separates greenstone (antigorite with secondary magnetite) from pyrite; no material appears to have crossed this barrier. If the pyrite was derived by contact metasomatism caused by the original gabbro, the subsequent serpentinization of this gabbro should have affected the actinolite associated with the pyrite. As it is, no traces of serpentinization exist in pyrite core samples.

To explain the above anomalies, three interpretations are possible. (i) That the pyrite and actinolite gangue formed after the serpentinization of the original gabbro of the greenstone. (ii) That the pyrite represents a contact metasomatic deposit separated from its serpentinized igneous parent by faults. Movement along these faults, coupled perhaps with hydrothermal solutions, obliterated the serpentine in the gangue and formed actinolitic rock. (iii) That the serpentinization of the gabbro was selective, took place outwards from the center of the intrusions, and did not affect the pyritic gangue along the margins. The complete lack of serpentinization of the gangue is however still unexplained.

None of the above interpretations satisfactorily accounts for all the phenomena of Carlota. As Spurr (87) has shown, it may be difficult to separate contact metasomatism from hypothermal action. For a complete explanation of mineralization, part of each of the above interpretations has to be combined with a theory of hydrothermal origin.

A Hydrothermal Origin.—A hydrothermal introduction of ore from below is the most likely origin of the Carlota pyrite. Although the source is thus pushed "more safely out of reach" (62), this mode of origin best explains all the observed phenomena.

On the evidence available, it is impossible to tell whether the ore was deposited from a hydrothermal solution or a liquid sulfide. However neither gossans nor drill cores show evidence of the spectacular cross-cutting intrusive sulfides postulated for other areas by Spurr (87).

Whatever the composition of the ore liquid, a thin tenuous fluid is necessary to explain the fine replacement of the limestones. "Fluid" is used in the sense proposed by Graton (32): "to embrace collectively the gaseous and the liquid states, or to designate either when expediency or ignorance may demand a non-committal term."

Speculations on the chemical nature of this fluid would be presumptuous. Ore samples from Carlota merely consist of a few drill cores lacking liquid inclusions suitable for analysis. In the words of Smith (85), it was felt that: "Such speculations, even though they appear to be not unreasonable, perform only a negative function of beclouding the real data."

Of the source itself, nothing is known. The ore fluid may have originated by a concentration of sulfides in a gabbroic "restmagma" (98). Or, it may have originated from an abyssal source (96) derived perhaps from the sulfide layer of Goldschmidt (28, 29). The former theory imposes less strain on the imagination, necessitates less distance for transport, and best accounts for the association of ore with gabbro (greenstone).

The theory of restmagma, as used here, implies that during crystallization

of the upper portion of the magma, the lower portion was being enriched in sulfides. Only after the upper portion had crystallized to gabbro, was the sulfide fluid forced upwards along the flanks of the gabbro.

The association of pyrite and gabbro suggests that they are related in time and came into place, one after the other, during the some orogeny. According to Loughlin (60, p. 681) the ore would be a deposit "associated with ferromagnesian rocks intruded during early stages of regional compression." Other areas in which copper ores, many of them pyritic, were preceded by basic intrusives, are listed by White (96).

The ore can be approximately dated by the age of the serpentinization. Mitchell (64), who along with others, believes that in Cuba, intrusion of igneous rock and serpentinization took place simultaneously, writes: "In southern Santa Clara, serpentines occur as serpentinous schists intercalcated within the Jurassic or older schists of the Trinidad Mountains. This would argue for a post-Jurassic age, and as the serpentine is comparable to that of northern Santa Clara, it is presumed to be of post-Jurassic pre-Maestrichtian age."

Synopsis of Mineralization.—The various features and anomalies of pyrite mineralization at Carlota have been discussed. The history of the deposit is presented stage by stage, in the following synopsis.

Stage 1: Injection and emplacement of gabbro with simultaneous folding, squeezing and shearing of the surrounding limestone. Different beds of limestone are successively exposed to contact metamorphism (?); the heat is rapidly removed and the development of skarn restricted. The magmatic heat may also be dissipated by any connate water present in the limestone.

Stage 2: Faulting and shearing; the gabbro intrusions are divided into smaller masses with actinolitization along their margins. The continued movement of limestone causes any thermal minerals which might have developed during Stage 1 to be destroyed.

Stage 3: In the gabbro, the self-oxidation of ferrous hydroxide in the residual liquid (82) leads to formation of magnetite and water. This water, plus any connate water still available in the limestones, causes serpentinization of the gabbros and the marginal actinolite, with development of antigorite and secondary magnetite.

Stage 4: Earth movements continue; faulting; development of actinolite gangue; introduction of early pyrite by replacement. The gabbro masses shrink slightly on serpentinization (Stage 3); pyrite moves upwards along their margins through limestone. Tension areas which develop along faults make space available in limestone for the later pyrite and its accompanying sulfides.

Stage 5: Period of differential post-ore adjustment. Marginal disturbance of orebodies. Late faulting with development of magnetite-chlorite schists along borders of serpentinized gabbro.

ACKNOWLEDGMENTS

This paper is part of a larger study sponsored by the Department of Geology, Columbia University and the Freeport Sulphur Company. The

writer is indebted to Professor Charles H. Behre for invaluable advice and encouragement, to Ed Lewko for assistance with the plane-tabling, and to Professor F. Gordon Smith for geothermometer determinations of pyrite. Technical help was rendered by Walter Sutcliffe of the University of Nottingham; Professor Paul F. Kerr, Professor Sidney Paige and Mr. Forbes Wilson read portions of the manuscript.

DEPARTMENT OF GEOLOGY,
CARLETON UNIVERSITY,
OTTAWA,
April 3, 1958

REFERENCES

1. Adams, Sidney F., 1920, A microscopic study of vein quartz: ECON. GEOL., v. 15, p. 623–664.
2. Allan, J. C., 1946, The San Telmo orebody, Spain: Inst. Min. Metallurgy Trans., v. 55, p. 339–371.
3. Allende, Roque, 1928, Yacimientos piritosos de la Sierra de Trinidad Mina "Carlota," Cuba: Direc. Montes y Minas Bol. de Minas, v. 12, p. 50–57.
4. Andrews, E. C., 1926, Igneous intrusions and ore deposits of the zone of flowage: ECON. GEOL., v. 21, p. 81–89.
5. Auger, P. E., 1941, Zoning and district variations of the minor elements in pyrite of Canadian gold deposits: ECON. GEOL., v. 36, p. 401–423.
6. Bain, George W., 1933, Wall-rock mineralization along Ontario gold deposits: ECON. GEOL., v. 28, p. 705–743.
7. ——, 1936, Mechanics of metasomatism: ECON. GEOL., v. 31, p. 506–526.
8. Barrell, Joseph, 1907, Geology of the Marysville mining district, Montana: a study of igneous intrusion and contact metamorphism: U. S. Geol. Survey Prof. Paper 57, 178. p.
9. Bateman, Alan M., 1942, Magmas and ores: ECON. GEOL., v. 37, p. 1–15.
10. ——, 1950, Economic mineral deposits: 2nd Edition, John Wiley and Sons, Inc., New York. 916 p.
11. Bichan, W. James., 1945, The cult of the indeterminate-whither replacement: ECON. GEOL., v. 40, p. 416–423.
12. Boydell, H. C., 1924–25, The role of colloidal solutions in the formation of mineral deposits: Inst. Min. Metallurgy Trans., v. 34, p. 145–252, 307–337.
13. Bruce, E. L., 1918, The Amisk-Athapapuskow Lake district: Canada Geol. Surv., Mem. 105, 91 p.
14. Calvache, Antonio, 1925, Resumen de historia de la mineria de Cuba: Bol. de Minas Habana, v. 8, p. 23–35.
15. Carstens, C. W., 1936, Zur genesis der norwegischen Schwefelkiesvorkommen: Deut. Geol. Ges. Zs. Bd., v. 88, H. 4, p. 257–268.
16. ——, 1941, Sedimentary pyrite occurrence: Kgl. Norske Videnskab. Selskabs, Forh., v. 14, p. 120–122.
17. ——, 1942, New study of the geochemical characteristics of Norwegian pyrite ores: Kgl. Norske Videnskab. Selskabs, Forh., v. 15, p. 1–4.
18. ——, 1943, The Co–Ni content of Norwegian pyrites: Kgl. Norske Videnskab. Selskabs. Forh., v. 15, p. 165–168.
19. Charleworth, G. H., 1935, The nature and occurrence of carbonate in veins: ECON. GEOL., v. 30, p. 502–517.
20. Coleman, Leslie C., 1957, Mineralogy of the Giant Yellowknife Mine, Yellowknife, N.W.T.: ECON. GEOL., v. 52, p. 400–425.
21. Collins, W. H., and Kindle, E. D., 1935, The life history of the Sudbury nickel irruptive: Royal Soc. Canada Trans., 3d ser., v. 29, p. 27–47.
22. Edge, A. B., 1928, Observations on the pyritic orebodies of southern Spain and Portugal: Int. Geol. Cong. 14th, Madrid, v. 3, p. 1207–1230.
23. Edwards, A. R., 1947, Texture of the ore minerals: Australasian Institute of Mining and Metallurgy Inc., 185 p.
24. Emmons, W. H., 1910, Some ore deposits in Maine and the Milan mine, New Hampshire: U. S. Geol. Survey Bull. 432, 62 p.
25. Faust, George T., Murata, K. J., and Fahey, Joseph J., 1956, Relation of minor-element content of serpentines to their geological origin: Geochim. et Cosmochim. Acta, v. 10, p. 316–320.

26. Finlayson, A. Moncrieff, 1910, The pyritic deposits of Huelva, Spain: Econ. Geol., v. 5, p. 357–372, 403–437.
27. Foslie, Steinar, 1927, Pyrite resources of Norway: Les Reserves Mondiales en Pyrites, Int. Geol. Cong. 14th, Madrid, v. 1, p. 159–184.
28. Goldschmidt, V. M., 1922, Der stoffwechsel der Erde: Norske. Vidensk. Selsk. Skr. Kristiania, No. 11, 25 p.
29. ——, and Peters, C., 1932, Zur Geochemie der Edelmetalle: Gesell. d. Wissenschaften, Gottingen, Nachrichten, p. 377–401.
30. Graton, L. C., 1909, The occurrence of copper in Shasta County, California: U. S. Geol. Survey Bull. 430, p. 71–111.
31. ——, McKinstry, H. E., and others, 1933, Outstanding features of Hollinger geology: Canadian Inst. Min. Metallurgy Trans., v. 36, p. 1–20, 606–618.
32. ——, 1940, Nature of the ore-forming fluid: Econ. Geol., v. 35, p. 197–358.
33. Gross, W. H., 1956, Direction of flow of mineralizing solutions, Blyklippen mine, Greenland: Econ. Geol., v. 51, p. 415–425.
34. Grout, Frank F., 1946, Microscopic characters of vein carbonates: Econ. Geol., v. 41, p. 475–502.
35. Hanson, George, 1920, Some Canadian occurrences of pyritic deposits in metamorphic rocks: Econ. Geol., v. 15, p. 574–609.
36. Hawley, J. E., 1952, Spectrographic studies of pyrite in some eastern Canadian gold mines: Econ. Geol., v. 47, p. 260–304.
37. Haycock, M. H., 1937, The role of the microscope in the study of gold ores: CIMM Trans., v. 40, p. 405–414.
38. Hegemann, F., 1937, Uber die Entstehungsweise der Kieserzlagerstätten von Sparneck in Oberfranken: Metallwirtschaft Bd. 16, H. 29, p. 719–720.
39. ——, 1950, Geochemische Untersuchungen uber die Herkunft des Stoffbestandes sedimentarer Kieserzlager: Fortschr. Miner., Bd. 27, p. 45–46.
40. Hess, H. H., 1933, The problem of serpentinization and the origin of certain chrysotile asbestos talc and soapstone deposits: Econ. Geol., v. 28, p. 634–657.
41. Hickok, William O., 1933, The iron ore deposits at Cornwall, Pennsylvania: Econ. Geol., v. 28, p. 193–255.
42. Hill, Patrick Arthur, 1953, The gossans of the Minas Carlota: A report to Diaz de Villegas Contratistas, S.A., Habana, Cuba. 23 p.
43. Holden, Edwin C., 1913, Report on the Carlota Mine, Cuba: Submitted to the Davison Chemical Co. Baltimore, U.S.A.
44. ——, 1914, Report on Carlota development: Submitted to the Davison Chemical Co. Baltimore, U.S.A.
45. ——, 1915, Report on the Carlota Mine, Cuba: Submitted to the Davison Chemical Co. Baltimore, U.S.A.
46. Hurst, M. E., 1935, Vein formation at Porcupine, Ontario: Econ. Geol., v. 30, p. 103–127.
47. Ibach, R., 1940, Zur Entstehungsgeschichte de Kieslagerstätte von Kupferberg in Oberfranken: Zs. angew. Miner., Bd. 2, p. 114–152.
48. Irving, Earl M., and Cruz, David P., 1951, Geologic report on the copper-pyrite deposits of Rapu-Rapu island, Albay province: Philippines, Bur. Mines, Rept. Inves. No. 1, 24 p.
49. Ivanov, S. N., 1943, New data on genesis of pyrite deposits of the middle Urals: Acad. Sci. URSS, B., Ser. Geol. No. 1, p. 20–24.
50. Kanehara, Nobuyasu, 1935, Copper resources of Japan: Copper Resources of the World. Int. Geol. Cong. 16th, v. 2, p. 687–700.
51. Kania, Joseph E. A., 1936, Some notes on the origin of pyritic copper deposits of the mesothermal type: Econ. Geol., v. 31, p. 453–471.
52. Kano, Hiroshi, 1950, Relation between the cordierite rocks and bedded pyrite ore deposits in Taro district, Iwate prefecture: Japanese Assoc. Mineralogists, J. v. 34, p. 141–151.
53. Keys, M. R., 1940, Paragenesis in the Hollinger veins: Econ. Geol., v. 35, p. 611–628.
54. Kulp, J. L., Ault, W. U., and Feely, H. W., 1956, Sulphur isotope abundance in sulphide minerals: Econ. Geol., v. 51, p. 139–149.
55. Lindgren, W., and Ransome, F. L., 1906, Geology and gold deposits of the Cripple Creek district, Colorado: U. S. Geol. Survey Prof. Paper 54, 516 p.
56. ——, and Irving, J. D., 1911, The origin of the Rammelsberg ore deposit: Econ. Geol., v. 6, p. 311–313.
57. ——, 1926, Ore deposits of the Jerome and Bradshaw Mountain quadrangles, Arizona: U. S. Geol. Survey Bull. 782, 192 p.
58. ——, 1933, Mineral deposits: McGraw-Hill Book Co., New York, 4th Ed., 930 p.
59. Locke, A., 1926, Leached outcrops as guides to copper ore: The Williams and Wilkins Co., Baltimore, 175 p.

60. Loughlin, G. F., 1941, Comments on the origin and major structural control of igneous rocks and related mineral deposits: Econ. Geol., v. 36, p. 671–697.
61. Maucher, Albert, 1940, Uber die Kieslagerstätte der Grube Bayerland bei Waldsassen in der Oberfalz: As. angew. Miner, Bd. 2., p. 219–275.
62. McLaughlin, Donald, 1940, Fields of the economic geologists widen and their techniques improve: Mining and Metallurgy, v. 21, p. 1–6.
63. Merlich, B. V., 1945, Data on geology of 3rd International deposit: Acad. Sci. URSS, B., Ser. Geol. No. 4, p. 74–87.
64. Mitchell, R. C., 1955, The ages of the serpentinized peridodites of the West Indies: Proc. Kon. Akad. v. Wetensch., v. 58. Series B, p. 194–212.
65. Newhouse, W. H., and Flaherty, G. F., 1930, The texture and origin of some banded or schistose sulphide ores: Econ. Geol., v. 25, p. 600–620.
66. ——, 1931, Geology and ore deposits of Buchans, Newfoundland: Econ. Geol., v. 26, p. 399–414.
67. ——, 1941, The direction of flow of mineralizing solutions: Econ. Geol., v. 36, p. 612–629.
68. Palache, C., Berman, H., and Frondel, C., 1944, Dana's system of mineralogy: v. 1, John Wiley and Sons, New York, 7th Ed., 834 p.
69. Pek, A. V., 1943, Structure of Degtyarskoe and the ore field of the Leviha deposits: Acad. Sc. URSS, B., Ser. Geol., No. 1, p. 14–19.
70. Prucha, John James, 1956, Nature and origin of the pyrite deposits of St. Lawrence and Jefferson counties, New York: Econ. Geol., v. 51, p. 333–353.
71. Quattrochiocchi, Tullio, 1951, Nota sul ritrovamento di pirite entro gli scisti di letto della miniera di Niccioleta: Italy, Serv. Geol., B. v. 73, p. 77–84.
72. Rade, J., 1956, Notes on the geotectonics and uranium mineralization in part of the Northern Territory, Australia: Econ. Geol., v. 51, p. 354–361.
73. Roman, D., 1927, Les reserves de pyrite de Roumaniee: Les Reserves Mondiales en Pyrites, Int. Geol. Cong. 14th, Madrid, v. 1, p. 261–269.
74. Roso de Luna, I., 1946, Mas datos acerca de la genesis de las mesas piritosas de Sevilla y Huelva: Spain, Inst. Geol. y Min., Notas y Com. No. 16, p. 289–310.
75. Ross, Clarence S., 1933, Copper deposits in the eastern United States: Copper Resources of the World, Int. Geol. Cong. 16th, Washington, v. 1, p. 151–166.
76. Santos-Ynigo, Luis, 1949, Geology and pyrite deposits of southern Antique, Panay: Philippine Geologist, v. 4, p. 1–13.
77. Schneiderhohn, H., 1923, Metall und Erz: Neues. Jahrb., f. Min. G.P.B.B. 47, p. 1–38.
78. Schofield, S. J., 1926, The Britannia mines, British Columbia: Econ. Geol., v. 21, p. 271–284.
79. Schouten, C., 1946, The role of sulphur bacteria in the formation of the so-called sedimentary copper ores and pyritic ore bodies: Econ. Geol., v. 41, p. 517–538.
80. Schwartz, George M., 1944, The host minerals of native gold: Econ. Geol., v. 39, p. 371–411.
81. Seifert, H., Nickel, E., and Bruckmann, E., 1952, Studien am "Neuen Lager" der Kieslagerstätte von Meggen (Lenne): Opuscula Miner. at Geol. No. 1, 70 p.
82. Shand, S. J., 1947, The genesis of intrusive magnetite and related ores: Econ. Geol. v. 42, p. 634–636.
83. Smith, F. Gordon, 1942, Lineage structure and conditions of deposition of pyrite—a discussion: Econ. Geol., v. 37, p. 519–523.
84. ——, 1947, The pyrite geo-thermometer: Econ. Geol., v. 42, p. 515–523.
85. ——, 1952, Discussion—Alpine lead-zinc ores of Europe: Econ. Geol., v. 47, p. 347–349.
86. Smyth, C. H., Jr., 1912, On the genesis of the pyrite deposits of St. Lawrence county: New York State Museum Bull., No. 158, p. 143–182.
87. Spurr, J. E., 1923, The ore magmas: McGraw-Hill Book Co., New York, 2 vols., 915 p.
88. Stickney, A. W., 1915, The pyritic copper deposits of Kyshtim, Russia: Econ. Geol., v. 10, p. 593–633.
89. Teas, L. P., 1918, The relation of sphalerite to other sulphides in ores: Bull. Am. Inst. Min. Eng., p. 1917–1931.
90. Thiadens, A. A., 1937, Geology of the southern part of the Province Santa Clara, Cuba: Physiographisch-Geologishce Reeks No. 12, Utrecht, Holland, 69 p.
91. Uglow, W. L., 1917, Gneissic galena ore from from the Slocan district, British Columbia: Econ. Geol., v. 8, p. 643–662.
92. Umbgrove, J. H. F., 1949, Structural history of the East Indies: Cambridge Univ. Press, 63 p.
93. ——, 1950, The origin of deep-sea troughs in the East Indies: Int. Geol. Cong. 18th, Great Britain, Rept. pt. 8, p. 73–80.

94. Vogt, J. H. L., 1926, Magmas and igneous ore deposits: Econ. Geol., v. 21, p. 207–233, 309–332, 469–497.
95. Vogt, T., 1952, Flowage structures and ore deposits of the Caledonides of Norway: Int. Geol. Cong., 18th, Great Britain, Rept. pt. 13, p. 240–244.
96. White, Charles Henry, 1945, The abyssal versus the magmatic theory of ore genesis: Econ. Geol., v. 40, p. 336–344.
97. Williams, David, 1934, The geology of the Rio Tinto mines, Spain: Inst. Min. and Metallurgy Trans., v. 43, p. 593–678.
98. Wilson, Forbes, 1951, Report on Minas Carlota: Submitted to the Freeport Sulphur Co., New York City, 40 p.
99. Yeatman, Pope, and Berry, Edwin S., 1917, Report on the Carlota Mine: Submitted to the Davison Chemical Co., Baltimore, U.S.A.
100. ——, 1919, A supplemental report on the Carlota Mine: Submitted to the Davison Chemical Co., Baltimore, U.S.A.
101. Zavaritsky, A. N., 1943, On certain peculiarities of Bljava, Sibay, and Uchala pyrite deposits in the Urals: Acad. Sci. URSS, B., Ser. Geol. no. 1, p. 3–13.
102. ——, and others, 1950, The geology and metamorphism of the pyrite deposits of the Urals—a compilation: Akad, Nauk, SSSR, Moscow, 328 p.
103. Zavaritsky, V. A., 1947, On the metamorphism in the 3rd International pyrite deposit of the middle Urals: Acad. Sci. URSS, B., Ser. Geol. no. 2, p. 91–102.

APPENDIX

Orebody No. 1

Orebody 1, underlying Gossan 1 was worked by the Davison Chemical Company, and is the only orebody known from underground data. Other orebodies are known only from drillholes. The shafts and adits which led into Orebody 1 are now inaccessible but in 1951 their positions were remapped.

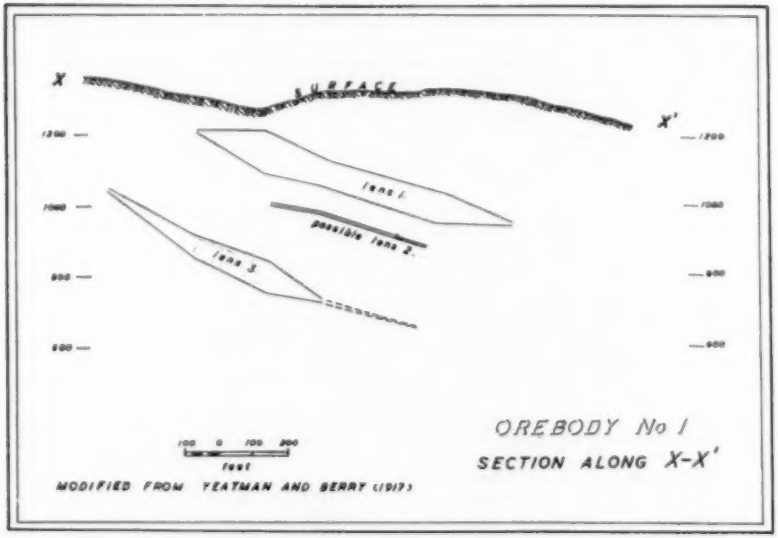


Fig. 16. Section along X–X′ of Figure 3.

The 20 holes put down by Phoenix and Davison were all on Orebody 1 and were spaced 200–300 feet apart on an east-west line. Two main pyrite lenses were located (Fig. 16). The upper or No. 1 lens, developed for a length of 2,000 feet and for a maximum thickness of 75 feet, overlies the eastern end of another major lens with a maximum thickness of 93 feet and a developed length of about 600 feet. The combined probable and developed ore for these two major lenses, as calculated by Yeatman and Berry (99), is 1,900,500 tons (Table 5).

TABLE 5

THE CALCULATED ORE IN OREBODY NO. 1

Lens	Probable ore	Developed ore
Lens No. 1	185,500 tons	1,030,100 tons
Lens No. 3	99,500 tons	585,400 tons

The dip of the ore lenses is reported as between 45 and 55° north (however at the New Shaft the dip is "69°") with a pitch (angle of inclination in plane of vein, measured from strike of vein) of about 30° east. At one point the pyrite of the upper lens of Orebody No. 1 comes within 60 feet of the surface. The deepest ore encountered by drillholes was in a portion of Lens No. 3 at a depth of 685 feet. According to Holden the lenses overlap along a fairly regular strike of N. 75° E.

Economic Geology
Vol. 53, 1958, pp. 1004–1037

STRUCTURE OF THE ORE DEPOSITS AT SANTA BARBARA, CHIHUAHUA, MEXICO

J. B. SCOTT

CONTENTS

PAGE
Abstract 1004
Introduction 1005
Geography 1005
Previous geological work 1006
Purpose and methods of present investigation 1006
Acknowledgments 1006
Geology of the Parral mining district 1008
General Geology of Santa Barbara district 1009
Shale 1009
Andesite 1010
Rhyolite 1011
Conglomerate 1011
Diabase, basalt, and scoria 1011
Unconsolidated stream sediments 1012
Structure 1012
Pre-mineral structure 1012
Post-mineral structure 1014
Geologic history 1015
Ore deposits 1015
History and production 1015
Mineralogy 1016
Primary sulfides and other metallic minerals 1016
Primary gangue minerals 1017
Oxide zone minerals 1017
Zoning 1017
Veins 1018
Surface outcrops 1018
Arrangement and pattern of veins 1018
Structure of veins 1020
Application to Santa Barbara district 1021
Simple vein structure 1023
Complex vein structure 1023
Location, shape, and rake of ore shoots 1028
Vein-shale structure 1030
Internal vein structure 1031
Paragenesis 1035
References 1037

ABSTRACT

The Santa Barbara mines are grouped in a circle around the village of Santa Barbara located in the Parral mining district, in southern Chihua-

hua, Mexico. The mines are operated by American Smelting and Refining Company and the bulk of the mineral production comes from eleven vein systems.

The pre-mineral rock types consist of a thick calcareous shale formation and andesite flows. The post-mineral rock types consist of dikes and sills of rhyolite and diabase, a thin conglomerate formation, basalt flows, and unconsolidated stream sediments. Pre-mineral faulting took place in two stages, forming four fault systems. Any fault within one system is similar in both strike and dip to another fault within that system. Movement along these faults, vertical in the first-stage faults and horizontal in the second-stage faults, formed openings, breccia zones, and in places horses and wedges of country rock in the faults. The location and explanation of these openings, breccia zones, horses and wedges are the main topic in this paper.

Hydrothermal solutions, emanating from depth, were introduced into the faults. The walls and breccia fragments within the faults were silicated and silicified and the high-temperature silicates, garnet, pyroxene, epidote, and idocrase (?) were formed. Accompanying and following the formation of the silicates, the sulfides sphalerite, galena, chalcopyrite, pyrite, and arsenopyrite, with associated gold and an unknown silver mineral were introduced with quartz, calcite, and fluorite. Most of these minerals replaced the silicates and altered shale. The parts of the faults where wide pre-mineral openings, horses or wedges were formed, were filled with quartz and a higher ratio of sulfides than the narrow portions of the faults. Quartz, calcite, fluorite, and barite were among the last minerals deposited. The veins are assigned to the hypothermal class of hydrothermal deposits.

INTRODUCTION

Geography.—The Santa Barbara district mines form a circle around the village of Santa Barbara in the Parral mining district, which is in the southern part of the state of Chihuahua, Mexico (Fig. 1). The Santa Barbara district, as it is commonly referred to, is an area about 6.5 km long north-south and about 5.0 km wide (Fig. 2). The mines are operated by a subsidiary of the American Smelting and Refining Company. Other mines in the Parral mining district are the La Prieta mine at Parral, also operated by a subsidiary of the American Smelting and Refining Company; the Esmeralda mine near Parral operated by a subsidiary of the Eagle-Picher Company; and the Frisco mine at San Francisco del Oro, operated by San Francisco Mines of Mexico, Ltd. Besides these major producers, a number of small companies and groups of miners are operating small mines in various parts of the Parral mining district.

Santa Barbara is located about 25 km, by oil surface road, southwest of the city of Parral and is connected to Parral by a branch line of the National Railways of Mexico. The north and west boundaries of the Santa Barbara district are located adjacent to the south and east boundaries of the San Francisco del Oro district.

The topography around Santa Barbara is that of mesa tableland cut by deep arroyos, which is typical of late youth. The average altitude is about 1950 m above sea level. Vegetation is sparse, consisting of scrub oak, desert type brush, and wild grass. The average precipitation is about 22 inches per year. About 10 km to the south of the district, the Sierra de Santa Barbara is characterized by steep cliffs of andesite flow rock.

Previous Geological Work.—Geological work was started in the early 1900's, soon after American Smelting and Refining Company formed a unit at Santa Barbara and began operations. J. E. Spurr was the first geologist to visit the mines and was followed by Basil Prescott, J. G. Barry, W. M. Davy, and Harrison Schmitt. In 1937 the position of resident geologist was created at the Unit and a formal program of surface and underground geological mapping was started by W. P. Hewitt and F. W. Farwell, under the direction of T. P. Clendenin. This work has been continued, intermittently, up to the present time by various geologists and mining engineers. Published work on the Santa Barbara geology consists of an article by Harrison Schmitt

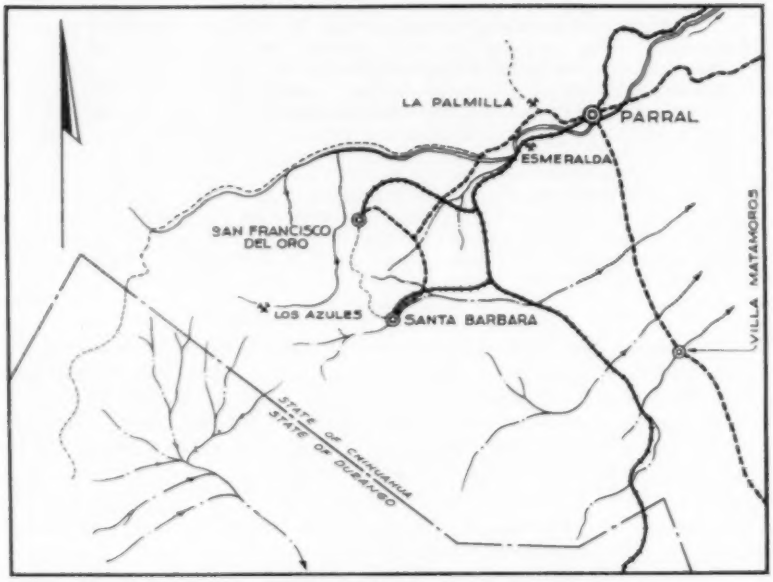


FIG. 1. Index map of Parral mining district, Chihuahua, Mexico.

(23); an account of the geology, accompanied by a surface map and two vertical sections, by M. D. Kierans (10); and more recently a discussion of high temperature minerals by V. T. Allen and J. J. Fahey (1).

Purpose and Methods of Present Investigation.—This paper was written during the fall of 1957. The field work was done, intermittently, over a period of seven months in conjunction with the regular duties of the resident geologist at the Santa Barbara Unit. The purpose of this study is to describe the structure of the veins and the relation it has to the location of ore shoots.

Acknowledgments.—The author is indebted to Mr. C. F. Jordan, former General Manager, and Mr. W. J. Nock, present General Manager for the

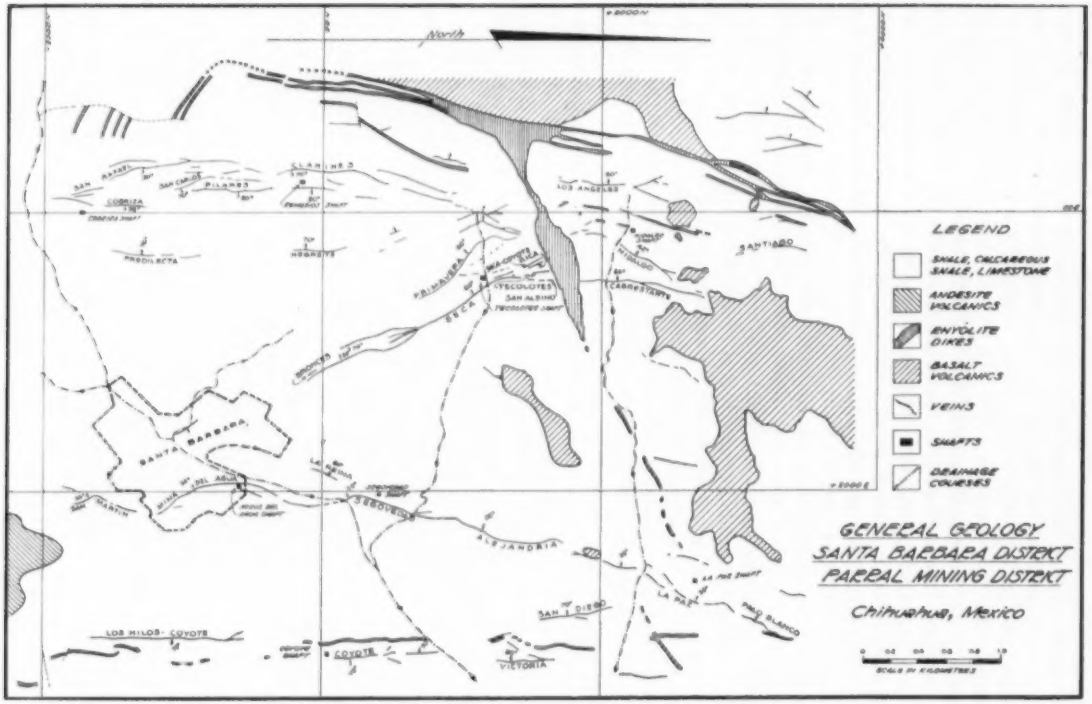


FIG. 2. General geology, Santa Barbara district, Parral mining district, Chihuahua, Mexico.

Mexican Mining Department of American Smelting and Refining Company, for permission to undertake the work and publish the results. He is also indebted to Mr. A. B. Williams, Unit Superintendent of the Santa Barbara Unit, for his aid and support during the preparation of this paper. Gratitude is expressed to Mr. T. P. Clendenin, Chief Geologist for the Mexican Mining Department who read and criticized the paper and offered much helpful information. Mr. David Wortman, Chief Engineer at the Santa Barbara Unit, gave many hours of critical discussion when the paper was still in the planning stage, and read and criticized the first draft. The writer has used the underground and surface maps prepared by the earlier geologists and mining engineers, and the great help these maps contributed toward the writing of this paper is acknowledged.

Geology of the Parral Mining District.—The most recent map showing the geology of northern Mexico that has been published is the Twentieth International Geologic Congress Map of Mexico (7). An earlier geologic map of northern Mexico was published by P. B. King (12). This map has been included, but at a smaller scale and with less detail, in a map of North America by the Geological Society of America (27). The geology of northern Mexico has been covered in papers by V. R. Garfias, and R. C. Chapin (6), E. O. Hovey (8), L. B. Kellum (9), P. B. King (11), and R. E. King (13).

The Parral mining district is in the border zone between the physiographic provinces of the Central Plateau and the Sierra Madre Occidental (9). The Central Plateau is equivalent to the Mexican Highland division of the Basin and Range province of the southwestern part of the United States, and has the characteristic isolated mountain ranges generally trending north, separated by wide alluvium covered basins. The Sierra Madre Occidental is a heavily dissected lava plateau, composed of a great thickness of bedded volcanic rocks of Tertiary age, which have suffered faulting and deformation at places but in many areas remain practically undisturbed. Greatly deformed Mesozoic rocks underlie the Tertiary volcanics along the eastern and western margins of the Sierra Madre Occidental.

No description of the entire Parral mining district has been published; however, Paul Waitz (28), Harrison Schmitt (23, 24), G. S. Koch (14, 15, 16), M. D. Kierans (10), G. C. Marlow and J. M. Smith (20), G. K. Lowther and G. C. Marlow (19), and G. K. Lowther and E. B. Bell (18) have written about the districts near the cities of Parral, Santa Barbara, and San Francisco del Oro. Other accounts of nearby areas have been written by W. H. Weed (29), Ezequiel Ordoñez (22), F. W. Smith (26), and I. E. Wilson and V. S. Rocha (31).

A thick series of folded sediments of probable Cretaceous age are the oldest known rock types in the Parral mining district. These sediments consist mostly of shale and limestone, but some arenaceous lenses are found within the formation. Clendenin (4) reports a "light colored, highly silicified shale, almost like a fine grained quartzite" in the deepest horizons of the La Prieta mine at Parral. A similar occurrence, a highly silicified arenaceous shale, which resembles a fine grained quartzite, has been found below the deepest

workings at Santa Barbara. These sediments are overlain by a thick series of gently dipping volcanics of probable Tertiary age. Schmitt (24) states that near Parral, both the volcanics and sediments are broken by great faults that generally strike north; are cut by a variety of dikes, and intruded by a small stock of quartz monzonite. Some of the veins follow these faults and dikes.

In the San Francisco del Oro-Santa Barbara portion of the Parral mining district, the veins are almost totally confined to fault zones within the shale. The only exception is in the southern part of the Santa Barbara district where a vein, outcropping in andesite, extends down into the shale. Also, in contrast to certain veins near Parral, the veins do not follow dikes, but instead are cut by the dikes. The veins at San Francisco del Oro are found in a system of relatively short fractures; whereas at Santa Barbara they are found along very long and persistent fractures.

A discovery of ammonites near the La Palmilla mine by Dr. J. Friedlander in 1906 (3, p. 174), dates the shale in the Parral district as middle Cretaceous (Gault-Vraconnien stage). No ammonites have been found in recent years and since the circumstances of the original find are uncertain the age assignment is regarded as tentative. A find of poorly preserved Aptychus close to Parral in some thin beds of limestone indicates that the age might be upper Jurassic (2), but this dating has not been used because of the poor condition of the fossils.

GENERAL GEOLOGY OF THE SANTA BARBARA DISTRICT

The surface geology of the Santa Barbara district is shown in Figure 2. The veins occupy fault fissures of small to large displacement that cut shale and, in the southern part of the district, andesite flow rock. The shale, andesite, and veins are cut by dikes and sills of rhyolite and diabase. These rock units are overlain unconformably by a gravel formation and basalt flows. The andesite to the south, unconformably overlies the shale. Several kilometers beyond the southern edge of the district, basaltic scoria plugs are present and cut through the andesite flows. The shale within the Santa Barbara district is folded into what appears to be an anticlinorium, and the veins are found on both limbs of the structure. The geology of the Santa Barbara district is closely related to that of the San Francisco del Oro district. Both districts have the same formations, except for the andesite which is lacking in the latter, and the structure is quite similar.

Shale.—The oldest known rock type, and the most widespread, is a thick calcareous shale formation. While this formation has not been traced into the shale known at and around Parral (Fig. 1), the two are lithologically similar and are thought to be the same or nearly the same in age. The shale, as Koch (14, p. 4) mentions, might better be called argillite if the name shale were not already so well established locally. In contrast to the behavior of most shales, the shale at Santa Barbara is strong enough to stand for long periods of time without support, even at long distances from the veins, where it has not been subjected to intensive silicification and silication. Very little

timbering is required and then only in fault zones and some broken zones found at sharp folds. Many open fractures are found in the shale, which give further indication of the rock strength.

The shale is hard, nonporous, impermeable, and highly indurated. The color ranges from blue-grey to black, and the composition varies from non-calcareous shale to almost pure limestone. The proportion of calcareous beds is not known, but it varies both laterally and stratigraphically. In general, the proportion of calcareous shale increases with depth, there being places at the deeper horizons where white calcareous bedding makes up about ten percent of the shale. Most of the shale is very fine grained and in places it is so massive that it has the appearance of hornfels. However, in other places it becomes quite granular, but this is due to arenaceous lenses or to recrystallized calcite. Pyritiferous bedding planes are common throughout the formation.

No marker beds are known to exist within the formation. The arenaceous lenses are not continuous enough to serve as marker beds. Neither the top nor bottom of the formation is known. Some deep drilling from the lowest workings would indicate that the base of the beds lies in excess of 700 m from the surface, but it is not known whether or not some of the beds are repeated by folding or faulting. Downward drill holes from the lowest mine levels in the Alejandria and La Paz mines have cut sections of a highly silicified arenaceous shale, resembling a fine grained quartzite, interbedded with black shale. This is the only known occurrence at Santa Barbara. With depth, as a rule, the shale tends to exhibit more pronounced metamorphic characteristics. Bedding planes are smooth and show slickensides in many places. The beds range 1 to 40 cm in thickness. Cleavage is generally visible, but is not strongly developed except where it stands at a large angle to the bedding. Near the crests and troughs of folds, the shale assumes a slaty appearance.

In several localities within the district, especially just north of the village of Santa Barbara, a large number of carbonate concretions have been found in the shale. The concretions have diameters of 5 to 50 cm and are generally oblong and slightly flattened parallel to the bedding. The concretions are dense and hard, black in color, and composed of calcium carbonate. Reports of fossils in concretions in other Cretaceous shales in the Western Hemisphere (30), prompted the writer to examine hundreds of the concretions for possible fossils. To date, the results have been negative.

Andesite.—The next rock type is a series of andesite flows, located in the south-eastern part of the district. These flows are probably Tertiary in age, about the same age as the andesites found near Parral. They range in color from dark green to dark grey where unaltered and light brown to violet in the weathered zone. The flows rest unconformably on the shale. The contact between the shale and andesite is very uneven, suggesting that the erosion surface on the shale had much the same type of rough topography as is now present. The shale shows baking, alteration, and silicification ranging up to five meters in thickness at the contact. The andesite at the contact is very fine grained and shows vivid colors due to oxidized iron. The andesite assumes a porphyritic texture upward and becomes quite massive. At one place, a

rhyolite dike was found to cut up through the andesite establishing that the andesite is older. A vein that outcrops in the andesite was found by drilling to extend down into the shale. This vein is thought to be a continuation of one of the major vein systems of the district, but this has not been established. However, it appears that the shale was covered by the andesite when vein filling took place.

Rhyolite.—The next younger rock type in the sequence is rhyolite, which is found as dikes and sills throughout the district. The classification "aplite" might better be used if the name rhyolite was not so firmly established locally and in the literature in both the Santa Barbara and San Francisco del Oro districts. The rhyolite is pink, brown, and white. It contains about 5 percent quartz phenocrysts averaging 2 mm across in a fine-grained groundmass. The dikes and sills are persistent in both the vertical and horizontal sections. In surface expression, the dikes form bold outcrops. One of the most prominent topographic features of the district is the "bufa," a high knob formed by a very wide dike located near the western edge of the district. The dikes vary in both dip and strike, but most strike north. However, some of the dikes show a S 70° W trend, which is not parallel to any veins, but is almost parallel to the strike of one of the post-mineral fault groups. The dikes are found to be rather constant in width, with the exception of the dike that forms the "bufa." This dike is about 200 m wide at the surface, but in the lowest workings, some 500 m below in the Tecolotes-Hidalgo mines it is only 20 m wide. Schmitt (23) comments that the structure of the dikes indicate a possible intrusive at shallow depth. As a rule, the dikes parallel the vein systems and therefore it seems possible that the dikes are an expression of fractures. In the northern part of the district, narrow veins are found adjacent to the dikes, and even within a dike zone. This relationship is not clear. One dike beyond the southern border of the district was traced from shale up into andesite. The character of the dike changed markedly at the shale-andesite contact and then the dike dies out after extending about 25 m up into the andesite.

Conglomerate.—In several places within the district, a thin formation of cemented gravel or conglomerate is found between the shale and overlying basalt. At most points on the surface, the formation is covered by basalt talus and is, therefore, very inconspicuous. In other places, the formation is completely absent. This unit is not mappable and is not shown on the surface geology map of the Santa Barbara district. The formation consists of pebbles, small boulders, some sand, and has been cemented by calcite. The fragments are composed of shale, limestone, rhyolite, and several types of andesite.

Diabase, Basalt, and Scoria.—These rock types have been grouped together because of similar chemical composition and because the types are thought to be nearly the same in age. The diabase is found throughout the district in the underground workings as scattered dikes and sills. The diabase is fine grained, but in some of the wider dikes and sills, becomes slightly granular and shows needles of augite. In a few of the dikes, disseminated pyrite is quite prominent. These dikes mainly follow post-mineral cross faults and cut

the veins in many places. It is thought that the dikes are the feeders of the basalt flows found on the surface.

In general the basalt is only found in areas of high elevation as a cap rock. However, to the east of the district, basalt has been found at relatively low elevations.The basalt is dark grey to black in color, is hard and dense, and breaks with a conchoidal fracture where it does not have a high ratio of vesicles. Koch (14, p. 9) reports that the basalt in the San Francisco del Oro district consists of "85 percent feldspar and pyroxene, in the ratio of 3:1, 10 percent olivine phenocrysts, and 5 percent vesicles, most of which are partly filled with calcite." The bases of the flows show that at the time of extrusion, the erosion surface was one of very gentle topography.

About three kilometers south of the southern edge of the Santa Barbara district, three basaltic scoria plugs are present. The scoria clinkers have an average diameter of 10 cm, are red in color, and are highly vesicular. Erosion has removed all traces of any scoria cones, but the diameters of the plugs, which range from four to seven meters, indicate that a large volume of material might have issued from these vents. The plugs cut through andesite. No basalt flows are found adjacent to the plugs, but a large amount of basalt float is found in the general area, indicating that flows may have been present at a higher elevation, but have disappeared through erosion. It is thought that these plugs might be one type of feeder for the basalt flows found within the district.

Unconsolidated Stream Sediments.—The youngest formation found within the district consists of unconsolidated sediments occurring along the drainage courses. The sediments include boulders, gravel, and sand. These sediments were derived from shale, limestone, rhyolite, several types of andesite, basalt, welded tuff and from the veins in the district, the latter contributing quartz and minor amounts of heavy minerals, including gold.

STRUCTURE

The structure will be discussed under two headings, pre-mineral and post-mineral, to conform with the major periods of structural activity.

Pre-Mineral Structure.—Soon after deposition and consolidation of the shale, horizontal forces began to be applied in a northeast-southwest direction. These forces resulted in the formation of an anticlinorium. Work by Koch (14, p. 4) on the north end of the structure, at San Francisco del Oro shows that it had a N 28° W trend and a 12° north plunge. At the south end of the structure at Santa Barbara, no definite surface interpretation could be made except that a very complex anticlinorium is present and has a N 30° W trend. The detailed structure is very complex because the individual shale beds are thrown into complicated drag folds and are broken by numerous small faults. However, underground mapping in a crosscut 2.7 km long, that extends from the Segovedad shaft to the Cobriza shaft area, gave a very definite picture of an anticlinorium. The west limb seems to dip more steeply than does the east limb. Examples of reverse movement along the bedding planes or as faults are very common in the underground workings.

Koch (14, p. 31) gives an excellent discussion on the possible origin of the pre-mineral fault system in the San Francisco del Oro district. He defines two periods in which forces formed sets of fractures, and has designated the latter as the Frisco and Transvall sets in the first period, and the Cobriza and Footwall sets in the second period. The reader is referred to his paper for the complete discussion. However, for convenience, a portion of his paper is quoted here and one of the illustrations reproduced:

The vein fractures of the Frisco mine were formed, the writer thinks, in two stages, as illustrated by Figures 18 and 19. In the first stage, the fractures of the Frisco and Transvaal sets were opened as a system of two sets of conjugate shear fractures in response to a tensional stress directed nearly horizontally at right angles to their strike combined with a compressive stress directed nearly vertically. In the second stage the fractures of the Cobriza and Footwall sets were opened as a second system of two sets of conjugate shear fractures in response to a tensional stress directed somewhat similarly to the tensional stress of stage one but plunging downward to the east, in fact a direction about normal to the attitude of the Transvaal vein set, combined with a compressive stress directed more nearly horizontally than vertically. These fractures of the second stage have a two-fold importance. Not only were they available for ore deposition, but of even greater significance, the forces which opened them also reopened the earlier formed fractures of the Frisco and Transvaal sets and so made the whole block of ground now occupied by the Frisco mine an especially favorable place for ore deposition.

Fig. 19. Deformation scheme. Isometric block diagrams. The upper diagram shows the planes of the Frisco and Transvaal sets of the first stage of deformation and the orientations of the greatest (P_1) and least (R_1) principal stress axes, both of which lie nearly in an E–W vertical plane. The lower diagram shows the planes of the Footwall and Cobriza sets of the second stage of deformation and the orientation of the greatest (P_2) and the least (R_2) principal stress axes; each lies nearly in a vertical plane, P_2 striking north–south, and R_2 striking east–west. In each stage, the intermediate principal stress axis (Q_1 or Q_2) is, of course, the line of intersection of the fractures. (*Note: Koch's Fig. 19 is shown as Fig. 14, page 1035.*)

The veins in the Santa Barbara district, which are the expression of pre-mineral fractures, have been found to fall within the limits of four fracture systems, each system showing a characteristic strike-dip trend that is different from the other three systems. Also, it is known from field evidence that two of these systems are older than the other two, and that two periods of movement took place in at least one of the fracture systems. The rake of some ore shoots suggests that oblique movement took place, but other ore shoots suggest two periods of movement. These four sets of fractures with their associated directions and orders of movement have been compared with those as described at the Frisco mine (23, p. 31), and a remarkable similarity exists. The discussion of the fracture theory in this paper will follow that of Koch's, except that the names of the fracture systems will be changed. This will result in the Frisco being changed to the Alpha; the Transvaal to the Beta; the Cobriza set to the Gamma; and the Footwall set to the Delta.

Schmitt (23) suggests that it is possible that about 3,000 feet (900 m) of volcanic material covered the sediments at the time of ore deposition. Thus, the thick cap of andesite rock might have been one of the factors to cause compressive stress and set up the conjugate shear fractures. It is thought that

some of these fractures might have extended up into the overlying andesite. The shear fractures, known as the Alpha and Beta, which formed the first stage of fracturing, both have an average strike of north–south, but the first has an average dip of 75° east, while the latter has an average dip of 70° west. According to the fracture theory, both of these fracture systems should have been normal faults, and ample evidence has been found in the field to confirm this. Since there are no marker beds within the district, it is not possible to determine the amount of the fault movement, but it is thought to be only moderate. One feature of these systems is their very regular strike. Another feature is that both appear to occur only in zones. Only two well defined zones are present within the district and they are separated by a width of 2.5 km.

The shear fractures, known as the Gamma and Delta, formed the second stage of fracturing. The Gamma set had an average strike of N 31° W with a dip of 58° west. The Delta set had an average strike of N 23° E, with a dip 51° west. Both of these systems are characterized by having an uneven strike, but are strong and extend over long distances. The Gamma system, having a strike of N 31° W, is parallel to the trend of the anticlinorium. Both surface and underground evidence indicate that the Seca fracture of the Gamma fracture system is located along the axis of the anticlinorium. What possible effect that might have had on the Gamma and Delta systems, will be discussed in the section on Veins. Again referring to the fracture system theory, the second stage shear fractures, instead of moving as normal faults, should have moved as strike-slip faults with a minor amount of vertical movement. Thus, the stresses of the second stage would have been relieved by movement along the fractures of the first stage where they were conveniently oriented. This would mean that some secondary movement, in a horizontal direction, would have taken place in some fractures of the first stage. Conclusive evidence has been found in the field to confirm the horizontal movement in the second stage fractures and the secondary horizontal movement in the first-stage fractures.

Post-Mineral Structure.—Following vein filling of the fractures, a series of faults and joints were formed. These are post-mineral since they cut or displace the veins. Much like the pre-mineral fractures, the post-mineral faults and joints fall within strike trend groups. The first has an average strike of N 80° E and contains most of the major faults while the second with an average strike of N 45° W contains both faults and joints. It has been noted that three types of faults are present:

1—Quartz filled faults
2—Calcite filled faults
3—Gouge filled faults

Strike-slip displacement along these faults is moderate, having an average of about 10 m. The maximum known strike-slip displacement is 60 m in a fault that cuts the Los Hilos–Coyote vein system. Vertical displacement in general is quite moderate, but in a few places it is known to be large. In the Clarines mine, it has been reported that a vertical movement of 90 m took

place on one fault (16). In most cases, a fault zone consists of a crushed zone 1 to 12 m wide with a center zone 0.1 to 1.0 m wide filled with quartz, calcite or gouge. Many of the gouge faults have diabase dikes in the center zone.

Some of the faults are very persistent and have been traced from the surface to the lowest levels of mining. Most have right-hand strike-slip displacements, but there are many known exceptions to this rule. Some hinge faults are known to exist, but they are few in number. It is thought that this series of post-mineral faults and joints extended over a considerable period of time, beginning soon after mineralization and continuing beyond the time when the diabase dikes and sills were intruded. In a number of places, diabase dikes and sills are cut by faults. About 4 km east of the southern portion of the district, an escarpment of recent age has been found. The escarpment extends along the base of some steep hills, cutting through the country rock and a small alluvial fan deposited at the mouth of a canyon. The escarpment is mostly covered by alluvium, but the break in the slope is very pronounced and can be traced for about 300 meters along the strike.

Geologic History

Although the sequence of geologic events in the Santa Barbara district is relatively clear, the lack of age determinations makes it difficult to assign each event to its correct position in the geologic time-scale. The oldest rocks are the shale formation, probably Cretaceous in age. After the shale was folded a period of erosion followed in which deep canyons with steep cliffs were formed. Andesite flows of probably Tertiary age were extruded filling the canyons first, then completely covering the shale erosion surface to a possible depth of 900 m. Next, the shale and the lower portion of the andesite were fractured in two stages, not necessarily separated by any great length of time. Simultaneously or soon after the formation of the second fracture stage, hydrothermal solutions entered the fractures to form veins. The rhyolite dikes and sills were then intruded into the shale and lower portion of the andesite. After a period of time, sufficient for erosion to strip away most of the andesite and reduce the surface to a gently rolling plain, gravel was deposited. Then another period of erosion followed during which most of the gravel together with more of the older rock was removed.

After mineralization, a series of faults and joints were formed in two strike trends. Diabase dikes and sills were intruded, some in the faults, and presumably fed the basalt flows that covered most of the Santa Barbara district. Scoria cones, to the south of the district, might have supplied part of this basalt. Another cycle of erosion followed, accompanied by more faulting until the present topography was formed.

ORE DEPOSITS

History and Production

Evidence is available that the veins at Santa Barbara were being worked in the pre-colonial period by Indians. This could be the reason why the first

veins discovered in the Parral mining district were found at Santa Barbara in about 1563 by an expedition of Spanish soldiers commanded by the Conquistador Don Francisco de Ibarra (W. V. Griffith, private report). The veins were initially worked for free gold and were being actively mined by the year 1600. The veins are reported to have contained as much as 200 ounces of gold and 160 ounces of silver per ton. The village of Santa Barbara, already having been destroyed once by a hurricane in 1579, had been rebuilt in its present location and had a population of 7,000 by 1600 (D. C. Shelton, private report). After this, the veins were worked intermittently until the middle of the 1700's, when the richer ores were apparently well exhausted, and by 1820 mining had almost ceased. In the late 1800's when it was found that the base metals could be produced at a profit, American Smelting and Refining Company formed a Unit at Santa Barbara, and by 1906 had put a 600-ton gravity concentrator into operation. Since the entry of American Smelting and Refining Company into Santa Barbara, except for the revolutionary period 1915 to 1920, the mines have been in continuous operation. At present, the Unit produces an average of 1,250 metric tons of ore daily.

Mineralogy

The mineralogy of the veins falls into two divisions, that of the primary sulfides below the water table, and that of the oxide zone above the water table. In the sulfide zone, a typical vein has the sulfides sphalerite, galena, chalcopyrite, and pyrite. The gangue minerals are quartz, calcite, fluorite, and a series of high temperature silicate minerals. In the oxide zone, the secondary minerals of zinc, lead, copper, and iron are present. A small amount of secondary sulfide enrichment is present at the base of the oxide zone.

Primary Sulfides and Other Metallic Minerals.—The most common minerals in this zone are sphalerite, galena, chalcopyrite, pyrite, and arsenopyrite. Small amounts of bornite, native copper, and hematite are found in the lower levels of some of the veins. The ore minerals sphalerite, galena, and chalcopyrite are found from the top of the sulfide zone to the lowest levels. The mineral referred to as sphalerite is really the iron-rich variety, marmatite. Generally the marmatite is quite massive and has a coarse crystal form. Galena occurs in two forms, the first very massive and showing a coarse crystal form. The second, while massive, has a fine crystal form and tends to be closely associated with pyrite. Chalcopyrite is rather fine grained and occurs as masses associated with pyrite or arsenopyrite. The arsenopyrite, although in small amounts near the surface, tends to increase with depth and in some of the lowest workings is very abundant. In general, all sulfides and gangue minerals become more coarse with depth. Schmitt (23) mentions this in his paper on Santa Barbara and Koch (14, p. 28) reports a similar condition at the Frisco mine.

Silver and gold are associated with the sulfides. The silver is closely associated with the galena and is probably carried mainly as an impurity in that mineral, though a little argentite may be present. The highest silver values occur with the fine-grained variety of galena. Gold is generally present

in very minor amounts, but in recent years rich gold concentrations have been found in a portion of the Seca vein.

Schmitt (23) recognizes three distinct kinds of primary ore at Santa Barbara. The first is a silicious lead-silver-zinc type, characterized by massive galena and sphalerite and containing minor amounts of chalcopyrite and pyrite. The second is a silicious gold-silver ore, distinguished by the absence of massive sulfides and the presence of silicate minerals such as pyroxene and garnet. The third variety, like the first, carries much massive sulfide, but in addition a large amount of silicate minerals.

Primary Gangue Minerals.—Quartz and calcite are the most common and widespread of the gangue minerals and are found in all the veins. Minor amounts of fluorite are found in all the veins, but in the lower levels of the Alejandria and La Paz mines in the northern part of the district, the amount increases and in places becomes the main gangue component. The quartz ranges from clear colorless, grey, to greenish in color. Most of the vein quartz is massive and dull in color. Lining the walls of vugs, the quartz is clear colorless to white and has a comb structure. Calcite is white to colorless, but in two places a violet variety has been found. Fluorite ranges from white to green in color and is fine grained.

Occurrences of orthoclase have been noted in several of the veins. Barite is found as narrow stringers within the veins, or in places as masses associated with calcite and quartz. The high temperature silicates belong to the garnet, pyroxene, and epidote groups. Schmitt (23) made the following identification of the silicate minerals:

Garnet (isotropic and birefringent)
Pyroxene (clino-enstatite)
Epidote (epidote and zoisite)
Idocrase (vesuvianite ?)

Allen and Fahey (1) report the presence of manganiferous hedenbergite from the 1,400-level of the Hidalgo mine.

Oxide Zone Minerals.—Above the water table, which is 50 to 120 m below the surface, the veins are vuggy, earthy, and show residual boxworks. The oxide portions of the veins are no longer being mined except on a minor scale by independent operators in the northern part of the district. The secondary minerals are anglesite, azurite, malachite, cerussite, jarosite, and "limonite." Additional secondary minerals as reported by Schmitt (23), are bornite, chalcosite, plumbojarosite, mimetite, pyromorphite, smithsonite, calamine, plattnerite, and hisingerite.

Zoning.—Schmitt and others have discussed the possibility of zoning in the district, but no definite conclusions have ever been presented on the district as a whole. C. A. Lee (private report) made the observation, "that the mineralogy of the veins suggests a semi-circular outline elongated N 45° W with more length than width." Schmitt (23) discussed zoning with depth and made the observation that copper increases somewhat with depth.

Although the mineralogy of the veins suggests something like a semi-circular outline, too many cases were found where the mineralogy does not

support this theory. The only definite statement that can be made is of zoning with depth. Copper, in the form of chalcopyrite along with arsenopyrite increases with depth.

Veins

All of the veins in the Santa Barbara district fill fractures in shale and andesite and have dips from 35° to vertical. Most veins, some of which are quite long, are longer than they are deep. The longest known continuous vein complex starting from the south at the San Martin mine and extending north to the Palo Blanco mine is 5.5 km in length. The average width of the veins is about 1 m, but in the ore shoots, widths of 4 to 5 m are common. In several of the wider ore shoots, veins of 15 m width have been mined.

Surface Outcrops.—Along the surface outcrops of the major veins in shale, it has been found that silicification and silication in places extend 10 to 15 m on each side of the vein. In the andesite, the degree of replacement and alteration is less, only extending out about 5 m on each side of the vein. Most of the veins have prominent outcrops and stand above the shale or andesite. In places they form ridges and, thus to some degree, control the topography of the district. In a number of places where the vein outcrops are not prominent, the silicified and silicated country rock adjacent to the veins, give rise to conspicuous topographic forms that have made it easy to locate the veins. Blind veins, having no surface outcrop, as yet have not been found in this district. However, there is no reason why such veins could not be present

Arrangement and Pattern of Veins.—The surface arrangement of the veins is shown in Figure 2. Of the veins shown, the majority fall into eleven vein groups, from which the bulk of the mineral production is obtained. The remainder of the veins are quite narrow, have very limited surface expression along the strike, and are seldom of ore grade. Grouping the veins according to strike and dip, discloses that they all fall within four strike-dip systems, any one vein within a system being similar in both strike and dip to any other vein within that system. In Table 1, all of the veins are listed according to systems. It will be noted that many of the veins shown in Figure 2 are not listed. This is because no data is available on the vein, or that the vein is in ground under control by other mining companies, or that the vein is only of minor importance and would not contribute to the geologic picture of the district. Since the four vein systems are the expression of pre-mineral fractures, they fall within the same strike-dip pattern of the fractures.

All four of the vein groups show intersections within their own group, indicating wedges or horses of country rock causing vein splits. The vein groups are discussed below.

The Alpha group veins have an average strike of N 2° E and dip 75° E. Within a single vein the strike is constant, but the dip is uneven. The veins show intersection at depth with veins of the Beta group in the eastern part of the district.

The Beta group veins have an average strike of north with a 70° west dip. Within a single vein, the strike tends to be slightly erratic and the dip is very

uneven. An extreme case of uneven dip is found in the Santiago vein. The dip changes from west to east for a short distance, then back again to the west. This is repeated, to some degree, in the Cabrestante vein, which becomes vertical for a short distance. The veins in the western part of the district, show intersections with veins of the Delta and Gamma groups.

The Delta group veins have an average strike of N 23° E with a dip of 51° W. Within a single vein, the strike is very erratic and the dip even. This uneven strike is shown rather well in the Mina del Agua-Palo Blanco vein system. It is suspected that a portion of this vein system will fall within the Beta group, and that the vein complex is a series of linking veins. Inspection of Figure 2 shows that the Mina del Agua-Palo Blanco vein shows two strike trends, one within the Delta group, and then for short distances one within the Beta group. Such a condition would result if a series of Beta fractures were present along this zone when the second stage of fracturing took place. The Delta fractures, having a strike-slip movement, would tend

TABLE 1

VEIN GROUP CLASSIFICATION

Alpha group	Attitude	Beta group	Attitude
Clarines	N 8 E, 70° E	Cabrestante	N 5 E, 85° W
Cobriza	North, 76° E	Coyote-Victoria	N 5 W, 77° W
Los Hilos-Coyote	N 7 E, 75° E	Los Angeles	North, 54° W
Pilares	North, 80° E	Predilecta	North, 70° W
San Carlos	North, 70° E	Rica	N 5 E, 55° W
San Rafael	N 6 W, 70° E	San Albino-Tecolotes	N 3 E, 80° W
		San Diego	N 7 W, 70° W
		Santiago	North, 65° W

Delta group	Attitude	Gamma group	Attitude
Hidalgo	N 27 E, 42° W	Primavera	N 30 W, 60° W
Mina Del Agua-Palo Blanco	N 21 E, 55° W	Seca	N 28 W, 57° W
La Reina	N 30 E, 80° W	Seca-Coyote	N 28 W, 57° W
San Martin	N 20 E, 55° W		

to follow the weak zones represented by the Beta fractures for short distances, before turning back parallel to the direction of shear. To some degree, this is confirmed by intersecting veins, such as the La Reina. The La Reina vein falls within the Delta group, yet the Mina del Agua-Palo Blanco vein turns off at a sharp angle and has a north strike for a short distance before turning back again to the general strike trend of the Delta group. Then, at the extreme south end of the Mina del Agua-Palo Blanco vein system, there is a distinct turn in the strike of the vein and it appears to have gone into the Gamma group. However, evidence available at the San Martin mine indicates that the west wall moved north in relation to the east wall, which would indicate that the vein was still within the Delta group. It is thought that the presence of the anticlinorium crest in this area had some effect on the strike and dip of the fractures as they cut across the structure. If this is the case, the fractures would be expected to exhibit the same characteristics, wherever they come into the axial trace of the structure. The fracture of the Delta set

turned parallel to the trend of the anticlinorial axis and possibly followed the reverse faults found on the limbs or the tension fractures that parallel the structure. Another vein that cuts the San Martin vein turns almost normal to the axis of the structure, and the dip is affected. In the western part of the district, this same relationship can be seen where veins of the Delta and Beta groups intersect the crest zone of the anticlinorium. The veins either turn parallel or normal to the trace of the structure axis.

The veins of the Delta group show numerous examples of intersections with veins of other groups. A large number of horses and wedges of country rock are present in this vein group.

The Gamma group veins have an average strike of N 31° W with a dip of 58° W. Within a single vein, the strike is erratic and the dip uneven in places. The Seca vein and the Coyote-Seca vein, the north extension of the Seca, along with the Primavera vein are the only major veins in the district found within this group. The Seca vein is located along the axis of the anticlinorium. In the case of the Seca vein, it is thought that the tension fractures located parallel to the axis of the structure served as weak zones and confined the strike-slip movement within the tension fracture zone. The tension fractures, having a dip normal to the folded bedding, in some cases, were filled with vein material. This resulted in a zone of veins with parallel strike and with dips ranging from east to west. In other places, it has been noticed that first stage fractures, where they cut across the crest of the structure, influenced the strike and dip of the Seca vein for short distances.

Attention is called to the fact that the grouping of the veins is very similar to that given the veins in the San Francisco del Oro district by Koch.

Structure of Veins

In the development of shear fractures such as those described in the section on structure, theoretically the fractures should form as perfect planes that show no variation in either strike or dip. However, since most rock units vary in chemical composition, physical properties, attitude, and have pre-existing joints and fractures that are zones of weakness, the resulting shear fractures will also vary in both strike and dip. Thus it might be said that all fractures are warped planes to some degree. Fault movement along these fractures, in either a vertical or horizontal direction, depending on the competence of the rock, would result in openings. A very brittle rock like andesite might become so brecciated during movement that any void would be filled with breccia. Even so, the fractured rock would give more area of contact to any possible mineral solutions that might be introduced at a later date and would, therefore, be especially favorable for replacement. In the case of a less brittle rock, such as a tough calcareous shale, the opening would have some brecciation around the margins, but the cavity might stand open indefinitely. A non-competent rock such as tuff, would be so plastic that any opening caused by faulting would be almost immediately filled.

Of course, much would depend on the depth below the surface and the consequent heat and pressure, but in an ideal situation and with the conditions

defined, a warped plane would result in openings on the steeper portions of normal faults, on the flatter portions of reverse faults, and on changes in strike or curves along strike-slip faults (Fig. 3). Any mineral solutions introduced in such faults should result in the wider portions of the veins being in brecciated or cavity zones. The important feature of this discussion on the location of the wider portions of the veins, is that within the Santa Barbara vein system, the width of the veins is roughly proportional to the grade of the ore. In other words, the wider the vein, the richer the ore.

Emmons (5) and Newhouse (21) report many deposits that show a warped plane condition. Schmitt (23) noticed a relationship between brecciated zones and width of vein at Santa Barbara and commented, "the widest part of the veins were areas of greatest brecciation along the pre-mineral fault planes, and thus the most favorable places for hypogene enrichment."

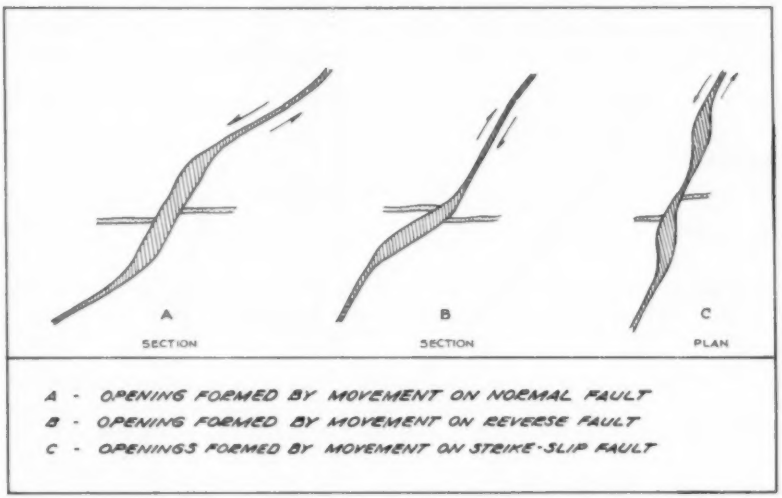


FIG. 3. Diagram showing openings formed by movement along faults.

Application to Santa Barbara District.—In the discussion of the Santa Barbara shales, it was shown that in contrast to the behavior of most shales, they are quite strong and many open fractures have been found within the formation indicating that they are quite competent and can stand for long periods of time without support. Thus, it would appear that the shale has the desired properties to meet the conditions as stated in the discussion on warped planes.

Initial faulting in the first stage of shear fractures, the Alpha and Beta, should have formed openings on the steeper portions of the faults since they would necessarily have been normal faults in accordance with the shear frac-

ture theory. In turn, movement on the second stage of shear fractures, the Gamma and Delta, should have formed openings at changes in strike, or curves, along the trace of the vein since they would necessarily have been strike-slip faults to again follow the theory. A slight amount of vertical movement would also be expected on this second set of fractures, since according to the theory, the compressive stress was not wholly horizontal in direction. Of course, minor strike-slip movement would also take place in the fractures of the first stage from the stresses of the second stage, and the fractures of the Alpha set would be opened wider. This would to some degree form openings on changes in strike, or curves, along the trace of the veins. Therefore, in sum-

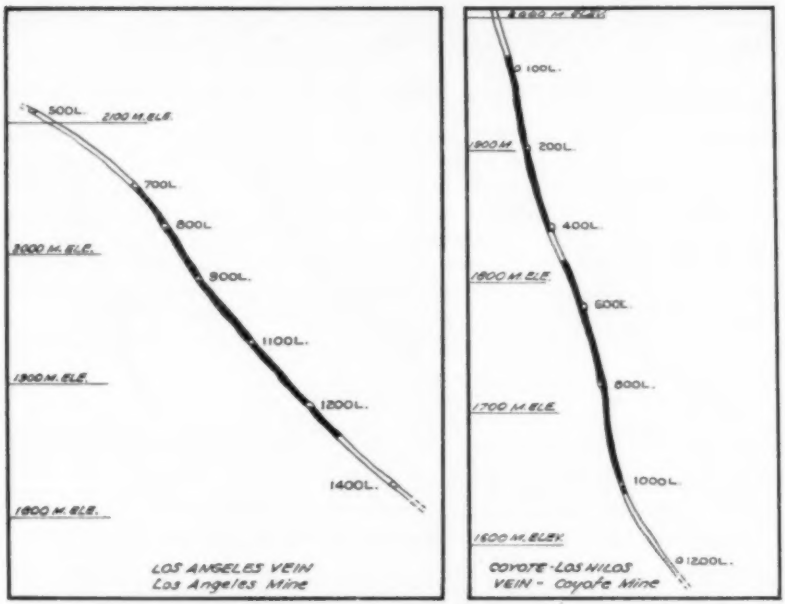


FIG. 4. Examples of ore shoots located in steeper portions of veins. Solid black indicates ore zone.

mary, in the first stage of shear fractures most movement would be in a vertical direction with minor movement along the strike, but in the second stage of shear fractures most movement would be strike-slip with minor movement in a vertical direction.

The field evidence to support the warped plane theory will be discussed under two headings, simple vein structure and complex vein structure. The simple vein structure designates a single vein uncomplicated by splits caused by horses or wedges of country rock or by vein intersections, which come under the complex vein structure classification.

Simple Vein Structure.—The proposed theory of warped fracture planes can be tested in a number of ways. One would be to try and find simple vein situations in the field and then apply the theory. Examination of vertical sections of simple veins, falling within the first stage of shear fractures, should show that on the steeper portions of the veins the veins widen. In Figure 4 are shown typical sections on two of the major veins in the district that fall in this fracture stage. It is not practical to show all the possible vertical sections, but as shown in the vertical sections illustrated, the ore zones in the simple veins are consistently found on the steeper portions of the veins.

For the simple veins, falling within the second stage of shear fractures, the changes in strike, or curves along the trace of the veins, should show widening of the veins. A portion of the underground geology on one level along the Mina del Agua-Palo Blanco vein is shown in Figure 5. On the portions of the vein that curve toward the west, surface or underground workings along the whole length of the vein shown, disclose ore at these locations and only at these locations. The reason for the location of the wide pre-mineral openings being in the vein curves to the west, and not in the curves

FIG. 5. Sub-surface map along a portion of the Mina del Agua-Palo Blanco vein showing location of ore shoots at changes in strike.

to the east, cannot be explained. Along the Hidalgo vein, also in the Delta group, the wide pre-mineral openings occur in curves to the east.

It is thought that the location of pre-mineral openings in curves of one direction and not in the other might be due to the amount of horizontal movement along the fractures, but this is not clear. However, once it has been established that a pre-mineral opening occurs in a curve of a certain direction, then all the other zones of wide vein, in that vein system, will also be found in similar curves.

Complex Vein Structure.—As was shown, in the case of simple vein structures, the thicker portions of the vein are found in the locations as defined by the theory. However, many places exist where the thicker portions of the veins are located in places that seem to be contrary to the theory. Examination of these places shows that they occur where a horse or wedge of country rock is present or where veins of different vein systems intersect. Analysis of each case has reduced the rather complex structure to a simple classification: That the thicker part of the vein is due to an opening formed by either vertical or horizontal movement. An example of each type of complex structure will be taken and a case history given on each.

Horses and Wedges.—This type of complex structure is the most common and economically the most important in the district. Movement of one wall against another in either a vertical or horizontal direction will cause sections of the hanging wall to break parallel to the direction of movement. This would tend to be the case, especially where there are marked changes in the dip or strike of the fracture. In general, most of the horses are small enough that they can be easily recognized for what they are. However, some of the wedges are so large, that the hanging wall and footwall veins have been classed as individual veins. The San Rafael-Clarines and Cobriza-Pilares veins are thought to be separated by a wedge. If such is the case, then it is the largest structure of that type in the district since it would be about 300 m wide and 1,500 m long.

Where a horse or wedge is encountered, invariably the hanging wall branch of the vein tends to be the wider and higher grade, whereas the footwall portion tends to pinch and becomes quite narrow. In several hanging wall branches, associated with both horses or wedges, the width of ore has exceeded 15 m. Gravity is thought to be the factor that controls this condition. However, it is known that during movement along the faults, especially those that had horizontal movement, some rotation of the horses or wedges took place. This would, to some degree, affect the location of the wider openings. Therefore, there are exceptions to the rule and it is sometimes necessary to make a detailed geologic study of each case to determine whether the footwall or hanging wall portion is the more favorable. A good example of such an exception is found in the Segovedad section of the Mina del Agua-Palo Blanco vein. This horse has been completely outlined by mining. The top of the horse is first encountered between the 500 and 700 levels and the bottom lies just above the 1,100 level. The horse is located slightly off the center of a vein curve. The hanging-wall vein is relatively narrow, while the footwall vein becomes quite wide. All of the footwall vein has been mined, while only a portion of the hanging-wall vein has been mined. At the top and bottom of the horse, where the two veins rejoin, the vein becomes very wide. An example of a horse showing the typical wide hanging wall and narrow footwall veins is found in the Seca vein. The horse has been almost completely outlined by mining and diamond drilling. Only a small portion of the footwall vein has been mined. The feature of this horse, is that the hanging wall becomes quite wide toward one end of the horse, showing that some rotation took place.

In most cases when a horse is encountered during the driving of development drifts, the splitting of the vein is so prominent that it is hardly overlooked. However, in a vein where horizontal movement took place along the fracture, the horse tends to pull toward one end or the other of a curve, and a more than average amount of rotation normal to the strike of the fault might have pressed the edge of the horse very tightly against the footwall and the resultant footwall vein might be so obscure that it would be overlooked. When the other edge of the horse is reached, if the development drift is not driven along the footwall side of the hanging-wall branch of the vein, it could again

be overlooked. It is possible that such situations exist, especially where no horse or wedge has been found on a major vein curve.

An example of a wedge, that was thought for a time to represent two intersecting veins, is the Mina del Agua-Novedad section of the Mina del Agua-Palo Blanco vein. The south end of the wedge starts at about the middle of the Mina del Agua ore shoot and continues north to about the middle of the curve toward the east that separates the Mina del Agua and Segovedad ore shoots. The length of the wedge at the surface is about 400 m. The hanging-wall vein of the wedge is called the Novedad and the footwall vein Mina del Agua. In Figure 6, it can be seen that the hanging-wall vein, as a whole, is much wider than the footwall vein, except in the southernmost section, where the footwall attains a width equal to that of the hanging-wall vein. From this, it is thought that slight rotation of the wedge took place, pressing

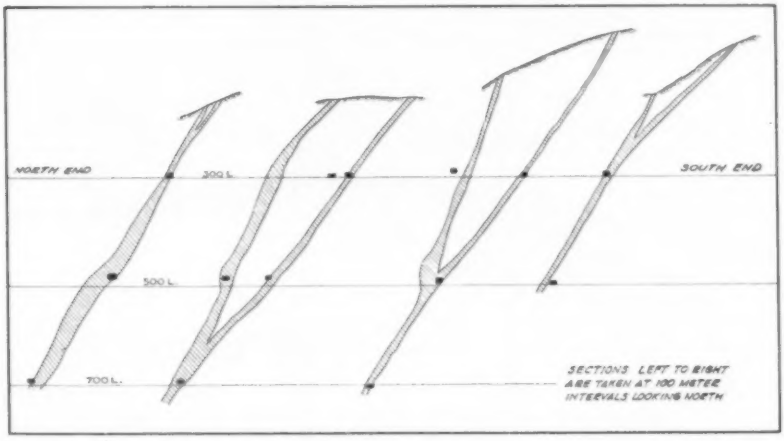


FIG. 6. Example of a wedge. The sections are taken along the Mina del Agua-Novedad section of the Mina del Agua-Palo Blanco Vein.

the hanging-wall side of the wedge against the hanging-wall fracture to the south and the footwall side against the footwall fracture to the north. The hanging-wall vein assumed width up to 15 m in this wedge zone.

Horses and wedges, similar to the type just described, have been found in almost every major vein or vein system in the district. In several cases, it has been found that a horse and wedge may exist on the same change-of-strike curve along a vein.

Many excellent examples of intersecting veins exist in almost every vein in the district, especially the Mina del Agua-Palo Blanco vein. However, about the best example in the district, and also the area with the most complex structure, is that where the Seca vein of the Gamma group intersects the Tecolotes and San Albino veins of the Beta group. Figure 7 shows four

underground levels in the intersection area to give an idea of the other factors involved. The Tecolotes and San Albino veins appear to be separated by a wedge, but the veins, though approaching each other, have not yet been found to intersect at the lowest level of mining, so this is only inferred. A portion of the possible wedge appears to have been displaced by the Seca fracture. Since the west wall of the Seca fracture, to follow the fracture system theory, would have moved toward the north, it might be possible that the displaced portion of the wedge is to the north along the hanging-wall extension of the Seca vein. To further complicate the structure, the Seca vein is located on or slightly to the west of the N 30° W trending axis of the anticlinorium.

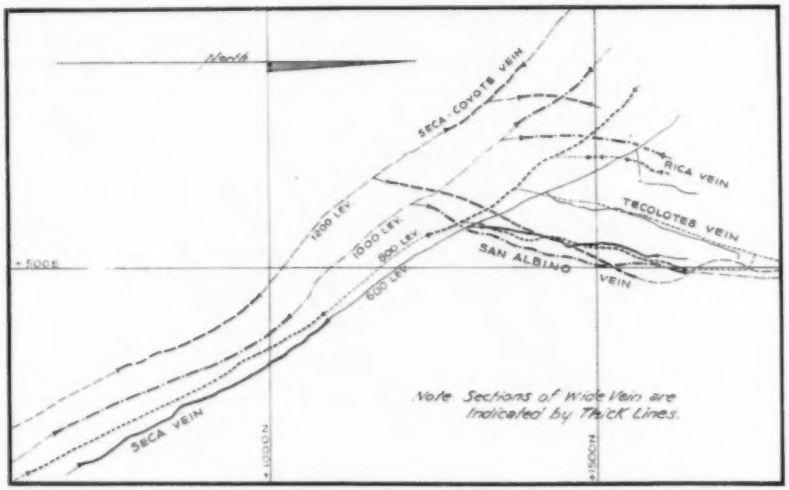


FIG. 7. Map showing a portion of sub-surface geology in the Seca vein and Tecolotes-San Albino veins intersection area.

A detailed examination of the Seca and Tecolotes-San Albino intersection area discloses that the locations of the wider zones of vein conform to the warped plane theory, with the exception of the possible wedge zone between the Tecolotes and San Albino veins. Figure 7 shows that the Seca vein has a curve toward the east, south of the intersection, and that north of the intersection in the Rica and Seca-Coyote veins other curves are present. The curves to the east in the Seca and Seca-Coyote and the curve to the west in the Rica, are zones of wide vein. Vertical sections taken along these curves show that the wide vein zones also are confined to portions of the veins that show a steeper dip.

Of interest is the fact that vein intersections do not appear to be especially favorable for wide vein zones. A number of examples of intersecting veins

can be shown where the vein does not widen to any degree. The Seca and Tecolotes-San Albino are the best example. However, an example can be shown where the older of two intersecting fractures was wedged open by movement on the second fracture, but this did not form a wide opening directly at the intersection, but only along the wedged fracture. Also this wedging open of a fracture tends to occur only in the portion of the fracture located in either the footwall or hanging wall of the second fracture, but never in both. Therefore, strike-slip and vertical movement in the second fracture, while wedging open the first fracture on one side, tends to pinch it tight on the other side. At the San Martin ore shoot, located on a portion of the Mina del Agua-Palo Blanco vein, mining between the 700 and 900 levels disclosed what appeared to be a double splitting vein (Fig. 8).

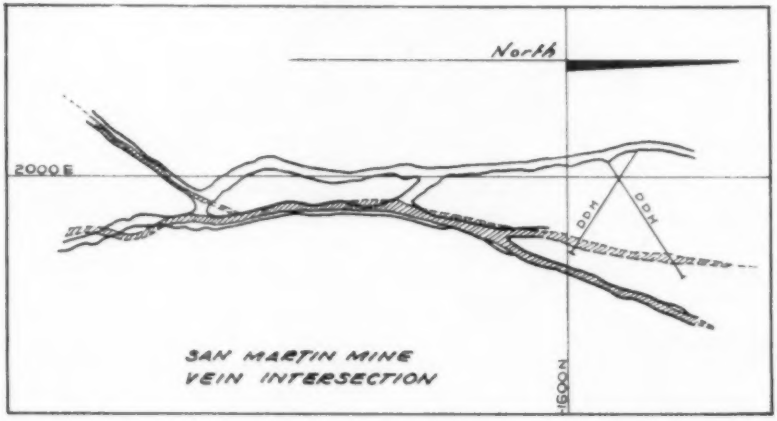


FIG. 8. Map of 900 level in San Martin mine showing vein intersection and displacement.

The location of the N 30° W trending axis of the anticlinorium, as discussed earlier, in the San Martin area is thought to have had some effect on the strike of the fractures. Therefore, while they do not follow the strike of the systems as required in the fracture theory, the San Martin vein is believed to fall in the Delta system, and the splits off the vein, in the Beta system. The San Martin ore shoot is located on a horizontal curve to the west. The hanging-wall split comes into the south end of the ore shoot and the footwall split comes into the north end of the ore shoot. The footwall split was ore grade and was mined 80 m to the north beyond the point where it leaves the San Martin vein. A geological model was made to determine if this was a double splitting vein, caused by spurs formed from the walls moving past each other during faulting, or if it was just a simple fracture intersection, offset by faulting. The model disclosed that the splits were too long along the strike to come under the double splitting vein classification but formed instead

a single offset. To reconstruct the order of events, the fracture of the Beta system was formed before the fracture of the Delta system. Strike-slip movement along the latter fracture, moved the east wall north in relation to the west wall. This offset the Beta system fracture about 50 m along the strike. Vertical movement tended to wedge the fracture open at the north intersection, and close it at the south intersection. Thus at the start of mineral

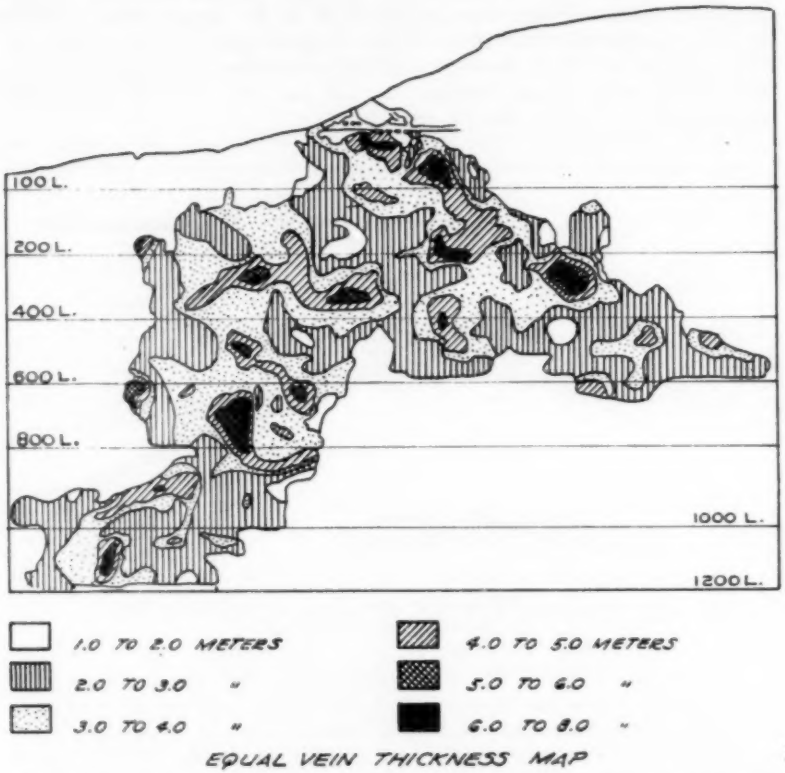


FIG. 9. Equal vein thickness map of an ore shoot in the Los Hilos-Coyote vein.

deposition, the wider openings formed in the horizontal curve of the Delta system fracture and the wedge in the north portion of the Beta system fracture, were available for vein filling.

Location, Shape, and Rake of Ore Shoots.—Previously it was stated that all fracture planes are warped to some degree. It was shown that the major warps are the controlling factor in the location of openings along the fractures. But besides the broad warps there are also minor warps along the whole

lengths of the fractures, both in open and in tight sections. This accounts for the pinch and swell character of the veins and is very noticeable along the narrower sections, where a slight swell or pinch in the vein is conspicuous. While this condition can be more easily seen in a narrow vein, it is necessary to go to the mined-out stopes where both walls of the vein have been exposed to obtain data on the condition. Figure 9 is an equal vein thickness contour map made of the longitudinal section of an ore shoot.

Figure 9 represents an ore shoot showing simple vein structure. Upon first observation, it appears that the vein pinches and swells at random with no definite patterns of wide and narrow portions of the vein. However, a study of the map (which is sometimes helped by drawing lines connecting the wider portions of the vein) discloses that a pattern is present. This pattern generally consists of a series of circular or elliptical units, each unit consisting of vein of wide character but with a center of narrow character, and with the units linked together like a set of interlocking rings. Two trends in this pattern are apparent, one that is parallel or almost parallel to the rake of the ore shoot and the other normal or almost normal to the rake. The dimensions of the circular zones, although not identical, are similar. This same condition has been found in every equal-vein thickness map made of the Santa Barbara veins. This suggests that the minor warps might have been the result of rather regularly spaced zones, such as weaknesses caused by joints and fractures; these zones, on intersecting with the shear fractures, would have tended to cause rather evenly spaced warps.

Underground mapping in a long crosscut that extends from the Segovedad shaft to the Cobriza shaft area, confirms the regular spacing of fractures and joints. Although the interval is not the same in all cases, it was noticed that groups of fractures and joints occur about every 70 or 140 m. Applying this on a larger scale and comparing Figure 10 (a longitudinal section of a vein with the outline of stoped areas shown) with Figure 9, an interesting similarity between the vein thickness contours and the spacing and linking of ore shoots is seen. The possibility that such a pattern of wide vein zones, shown in Figure 9, could apply to an entire vein system is not only reasonable, but probable. The presence of the major warps in the shear fractures, suggests that strong joints and fractures cut by the shear fractures, could very well have caused the marked changes in the strike found in some of the veins. This condition is well illustrated along the strike of the Mina del Agua-Palo Blanco vein, where the vein is thought to intersect older fractures. Changes in the attitude of the shale bedding and the joints and fractures are very likely the reason for changes in dip. The possibility that there are regular intervals between the ore shoots, because of the spacing of the weak zones intersected by the shear fractures, is very important.

Again, in the Mina del Agua-Palo Blanco vein, a rather constant interval between the major ore shoots is apparent. The average interval between the ore shoots is about 750 m. Along other veins this constant interval condition between ore shoots is not too obvious from the surface geology, but from the underground workings, on some of the veins, a very good constant interval

picture is obtained. Other veins show no interval relationship at all, but this might be due to the presence of complex structure zones.

In the early days of operation at this unit, most of the ore shoots were classed as being longer than they were deep. However, since then, as mining has progressed to deeper levels, the general classification has changed to that of equal lengths in the vertical and horizontal sections. About half of the ore shoots have the shape of the top portion of an hour glass and appear to be shortening with depth; others have vertical sides from top to bottom, and still others have the shape of the bottom portion of an hour glass and appear to be lengthening with depth. About half of the known ore shoots have a vertical or nearly vertical rake. Some of the ore shoots, among those classed as having

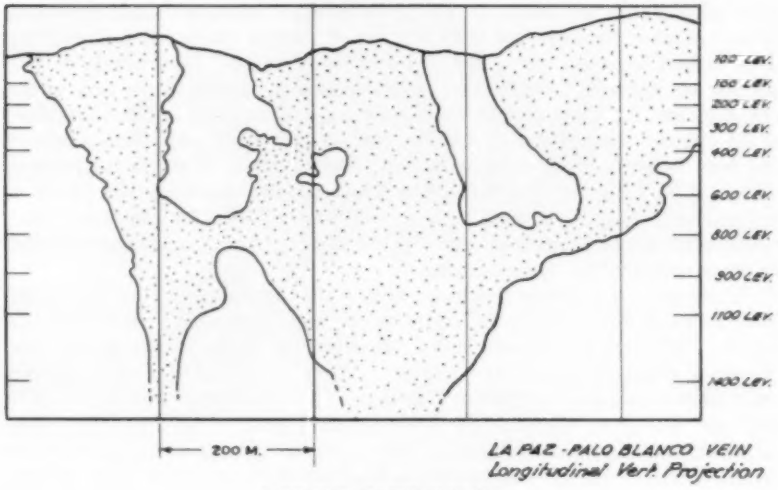


FIG. 10. Vertical projection of stope outlines map of the La Paz-Palo Blanco section of the Mina del Agua-Palo Blanco vein.

a vertical rake, appear to have both north and south rakes for short distances where a very narrow spot appears in the vein, but the ore shoot taken as a whole, has a vertical trend. A very noticeable rake to the north is shown by the Los Angeles ore shoot and a noticeable rake to the south is displayed by the Cobriza ore shoot. What appears to be a double raking ore shoot is located along a portion of the Los Hilos-Coyote vein (Fig. 9).

Vein-Shale Structure.—It is to be expected that the attitude of the shale bedding would have a bearing on the width of the veins. A fracture normal to the bedding would necessarily break the shale open with accompanying brecciation. Movement along such a fracture, if it was warped, would form openings. A fracture parallel to the bedding would follow and have movement along the bedding and thus tend to be very narrow. Any openings formed in

the fracture would tend to close. At the Frisco mine, this is reported to be the most important factor governing vein strength (14, p. 16). Contrary to this, at Santa Barbara the bedding appears to have little or no control over the vein width. Isolated examples where it appears that the bedding might govern the width of the veins, are found mostly in the minor veins in the northern part of the district. It is possible that the bedding exercises less control than expected because most of the fractures in the Santa Barbara district crossed the fold trends at angles from 20 to 60 degrees and the attitude of the bedding was, therefore, hardly ever parallel to the fractures. Even though most of the direct evidence seems to be negative, it is suspected that the bedding does exert more control on the veins than is indicated.

Only two major veins, the Seca and Primavera, strike parallel to the trend of the folding. The Seca vein is located near the crest of the anticlinorium. Not much control could have been exerted by the bedding since the vein is almost normal to the bedding, and tension fractures formed along the crest of the anticlinorium, would have provided a weak zone for the Seca fracture to follow. The Primavera vein, while dipping in the direction of bedding, is much steeper, and would have cut across the bedding planes. It seems reasonable that more fractures of the Gamma system should have been formed. The rarity of veins in the Gamma set suggests that the fractures might have been parallel to the bedding and that they were so tight that no hydrothermal solutions were introduced into them. Some of the larger folds on both limbs of the anticlinorium, having also formed tension fractures during folding, might be favorable locations for the presence of blind veins that would have strikes parallel to the trend of the folding. Detailed geologic mapping of the shale beds will be required to determine this and other questions pertaining to the relation of the vein-shale structure.

Internal Vein Structure.—The internal vein structure varies from vein to vein and also with depth. A typical vein is bounded on both sides by semi-parallel walls that are frozen to the vein. On both sides of the vein, the distance varying from a few centimeters to 15 meters, the country rock is silicified, pyritized, silicated, and in places shows disseminated sulfide replacement. Sub-parallel stringers of quartz and calcite are common. Depending on the vein, but mostly at depth, the vein-wall contacts become vague in places and the contact becomes a zone, several meters wide, of stringers in a matrix of country rock. In the veins the sulfides occur as narrow ribbons or bands, also as massive lumps or layered bands where shale fragments and masses of silicates were replaced. In both silicified and unsilicified country rock adjacent to the veins, and also at long distances from the veins, sufides occur as disseminated lumps and grains in bedded replacement zones. These replacement zones vary in dip and strike, following the bedding for a distance, then cutting across the bedding until another favorable bedding horizon is encountered. The question as to what constituted a favorable bedding horizon prompted the writer to make a study of drill cores where such replacement zones have been cut. In most cases, the replacement zone follows the more calcareous bedding. When the zone cuts across the bedding, it is in the form of very narrow quartz-calcite or silicate stringers that are generally barren of

sulfides except where a calcareous band is cut, whereupon sulfides commonly appear. This is shown in Figure 11.

Figure 11 suggests that the composition of the country rock might be a factor to be considered in the discussion of the location of ore shoots. If calcareous beds made up a very small portion of the shale formation and are also restricted to a limited number of horizons, their position might have been a very important factor. However, the calcareous content of the whole shale formation is quite high and the beds with a high calcareous content are found everywhere within the formation. Thus, it is thought that any influence of the country rock on ore deposition has been minor. It is thought that the composition of the breccia fragments within the vein might have a bearing on the degree of replacement achieved within that local part of the vein, and might be a reason for the higher than average metal content of zones within an ore shoot.

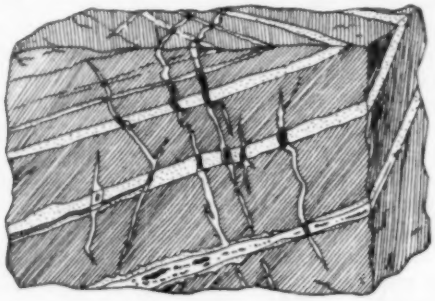


FIG. 11. Sketch showing replacement in shale.

Toward the ends of ore shoots, the veins are mostly filled with irregularly shaped fragments of country rock that have been silicified, silicated, and replaced around the fringes with sulfides. Towards the centers of ore shoots only half to three-quarters of the vein is apt to contain breccia fragments. These fragments have also been silicified, silicated, and tend to be more completely replaced by sulfides and quartz. There are places where the fragments have been completely replaced by alternate layers of quartz and sulfides, giving a cockade structure. This cockade structure is common throughout the veins (Fig. 12). The breccia zone is generally along the footwall of the vein, but in places is in the center and even adjacent to the hanging wall. The portion of the vein where there are no breccia fragments generally has a ribbon or banded structure. In places the quartz is quite massive with little or no structure.

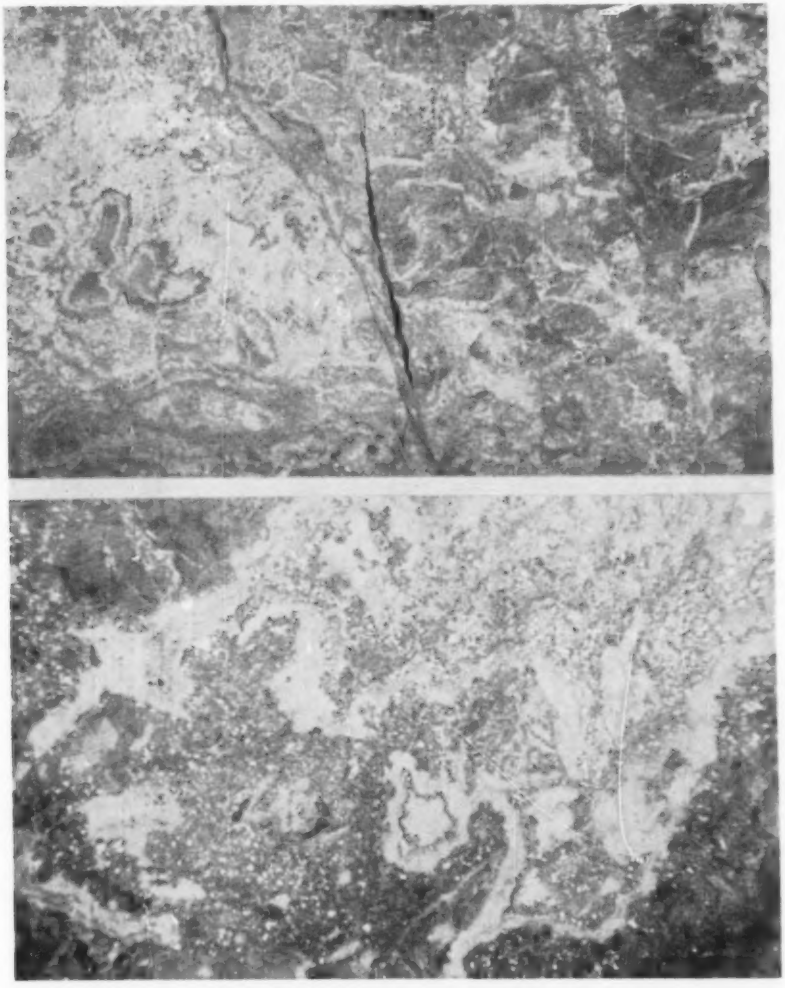


FIG. 12. Two examples of cockade structure, showing both complete and incomplete replacement of shale fragments. (top)—Part of the back in drift on Cobriza vein, 1,200 level, Cobriza mine; (bottom)—Part of the wall in sill on Cobriza vein, 1,200 level, Cobriza mine.

All the veins with ribbon and banded structure, indicate that they were subjected to dilation during vein filling (Fig. 13). On the 1,200 level of the Santiago vein there is a good illustration of this feature. A portion of the vein was broken across the ribbon structure three times, each vein filling

cutting across the previous fillings. Many vugs occur in the veins throughout the district, indicating that many openings were present, even along sections of narrow vein. However, most of the vugs occur within the ore shoots, the largest being between the 800 and 1,000 levels of the Cobriza vein. The vugs

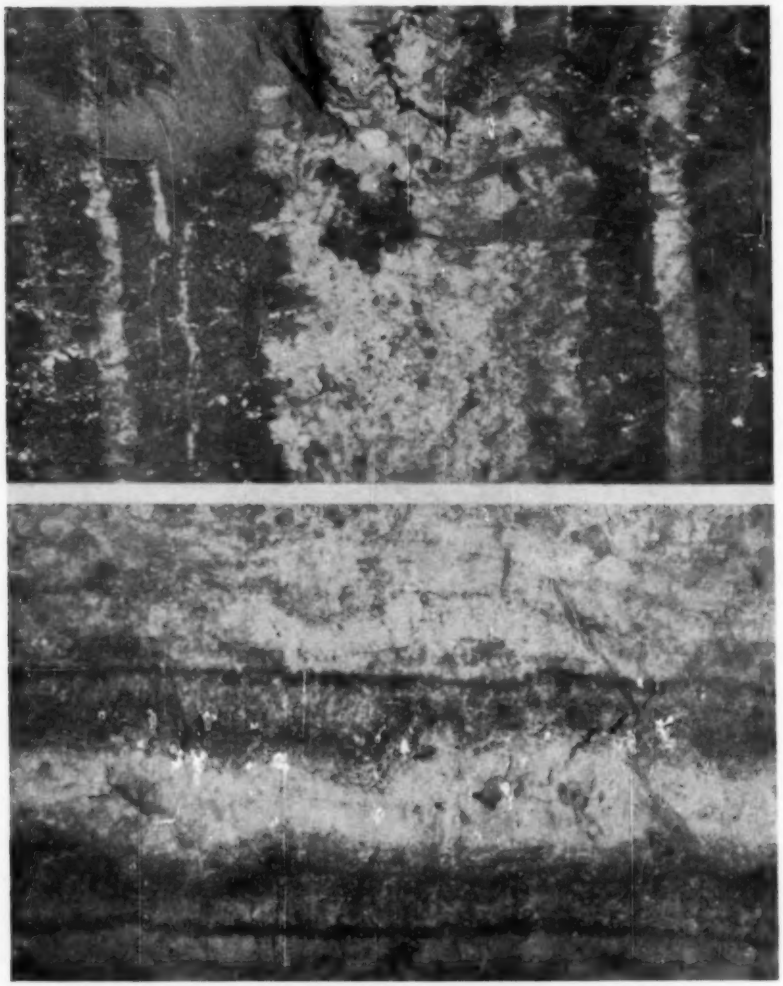


FIG. 13. Two examples of ribbon and banded structure. Both photographs taken of the back in drift on Seca vein, 1,400 level, Tecolotes mine. (top)—Shows massive sphalerite (dark) cut by quartz (white); (bottom)—Shows two small vugs with comb structure.

are quite large, ranging up to 40 cm wide, and the quartz crystals developed in the walls of vugs show a comb structure. Other gangue minerals and some of the sulfides in the walls of vugs show perfect crystal forms.

The veins generally end either by intersection with other veins or by pinching down until they are very narrow, and then fray out into a number of stringers. Very few examples have been seen of veins pinching down to a knife edge as is reported to be the case at the Frisco mine (14, p. 27).

For a number of years it has been known that the grade of Santa Barbara ore is roughly proportional to the width of the vein (23). Of course, isolated exceptions to this can be found, but they are very few. It is thought that where there were wider openings in the pre-mineral fractures, the decreased velocity of the upward rising mineral solutions as they came into these wider openings was the main factor contributing to the higher metal ratio of such places. It would seem that in zones of narrow fractures, the higher velocity

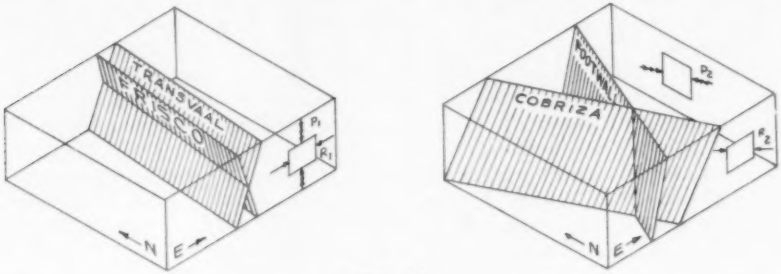


FIG. 14.

of the solutions would allow little time for precipitation or replacement. Otherwise, all of the veins regardless of width, would show the same metal content.

Paragenesis

Hydrothermal solutions, possibly emanating from the intrusive body suspected to be at depth, were introduced into the open fracture systems. The solutions contained ore metals with fluorine, sulfur, and possibly iron, magnesium and other elements. The silicates were formed by the interchange of constituents between the solutions and shale at a high temperature. Quartz and calcite were recrystallized, and fluorite and sulfide minerals were deposited.

Koch (14, p. 36) suggests that the bulk of the mineral matter at the Frisco mine was introduced at one time and not at different periods. Schmitt (23) gives three types of sulfide ore: Type I—Massive sulfide ore, Type II—Siliceous gold-silver ore containing abundant silicate minerals, Type III—Massive sulfide ore with abundant silicate minerals. This, of course suggests more than one period of vein filling at Santa Barbara. Schmitt also cites J. G. Barry's (unpublished report) observation that the high-temperature or silicate stage cut the low-temperature or solid sulfide stage. This would mean that the temperature rose to the silicate stage and then declined, with

sulfides being deposited in every stage. This seems reasonable, but such occurrences of high-temperature mineralization cutting the lower temperature mineralization must be scarce, because only a few have been seen by the writer. However, there are many occurrences of the lower temperature mineralization cutting the high-temperature stage. Whether this represents two different periods of vein filling or just long time lags between the reopening of the veins to allow more vein filling is not known. Since these occurrences are so numerous, it seems likely that at least two stages of vein filling are represented; however, the question is debatable.

It is the opinion of the writer, except for a minor amount of pre-silicate sulfides, that the high-temperature silicates with associated sulfides constituted the initial stage of vein filling. The veins of the silicate stage are characterized by very coarse crystals, almost pegmatitic in size. The best example of this is the Alejandria-La Paz section of the Mina del Agua-Palo Blanco vein. It might be mentioned again that deep drilling from the Alejandria and La Paz mines disclosed quartzite-like lenses at depth. This vein can be followed continuously to the south, passing from this high-temperature silicate stage of mineralization into a region at the south end that shows only epidote, the weakest recognized degree of silication. This, of course, suggests zoning. Schmitt (23) comments about gradation from one stage of mineralization to another in the San Albino and Cabrestante veins.

As vein filling progressed, the temperatures dropped, until at a late stage, deposition took place with little or no silicates. Barite appears to be later than the sulfides. It occurs within the veins, but cuts all sulfides and gangue minerals. Cross stringers of barite are common along a portion of the Los Hilos-Coyote vein. A late stage of fluorite is also present. It has been found where the veins are cut by fluorite-calcite-quartz stringers. Examples of this are found in many places along the Alejandria vein. A very late stage of deposition is represented by barren quartz veins that cut the older mineralized veins.

The birefringent garnet, reported by Schmitt (23), associated with the pyroxenes in some of the sphalerite ore, and the fact of the veins having been formed by replacement of shale suggested to Allen and Fahey (1) that the veins are pyrometasomatic replacement deposits. It is quite possible that a buried intrusive exists a short distance below the veins, and the factor of metamorphism, as indicated by the quartzite-like zones at depth, helps substantiate the presence of an intrusive. However, pyrometasomatic replacement deposits are characteristically irregular and bunchy, and seldom have large amounts of quartz gangue. The veins at Santa Barbara, even the high-temperature silicate type, are well defined and regular veins, and have a high ratio of quartz gangue vein material. Therefore, following Lindgren's (17, p. 694) classification, the Santa Barbara deposits are assigned to the hypothermal class of hydrothermal deposits.

Colonia Tecolotes,
Santa Barbara, Chihuahua, Mexico,
April 15, 1958

REFERENCES

1. Allen, V. T., and Fahey, J. J., 1957, Some pyroxenes associated with pyrometasomatic zinc deposits in Mexico and New Mexico: Geol. Soc. America Bull., v. 68, p. 881–896.
2. Böse, E., 1906, Excursions dans les environs de Parral: Guide des excursions, Congr. Geol. Intern., X Seccion, Mexico, no. 23, 16 p., 1 map, 7 fig.
3. Burckhardt, C. E., 1931, Etude synthétique sur le Mésozoique Mexicain, seconde partie: Soc. paléont. Suisse Mém., v. 50, p. 174.
4. Clendenin, T. P., 1953, Geological notes of the Prieta Mine, Parral district, Chihuahua, Mexico (paper presented at International Mining Days, El Paso, Texas).
5. Emmons, W. H., 1948, Certain ore shoots on warped fault planes: Am. Inst. Min. Met. Eng. Trans., v. 178, p. 58–81.
6. Garfias, V. R., and Chapin, R. C., 1949, Geologia de México: 202 p., Mexico City, Editorial Jus.
7. Hernandez Sanchez M. S., editor, 1956, Carta Geologica de la Republica Mexicana, Scale 1:2,000,000: Cong. Geol. Intern., XX Seccion, Mexico.
8. Hovey, E. O., 1907, A geological reconnaissance in the western Sierra Madre of the state of Chihuahua, Mexico: Am. Mus. Nat. History, Bull., v. 23, p. 401–442.
9. Kellum, L. B., 1944, Geologic history of northern Mexico and its bearing on petroleum exploration: Am. Assoc. Petroleum Geologists Bull., v. 28, p. 301–325.
10. Kierans, M. D., 1956, Minas de la Compania Minera Asarco, S. A., en Santa Barbara: Congr. Geol. Intern., Excursiones A-2 y A-5, Vigesima Seccion, Mexico, p. 101–108.
11. King, P. B., 1942, Tectonics of northern Mexico: Proc. Eighth Am. Sci. Cong., v. 4, p. 395–398.
12. ——, 1947, Carta geológica de la parte septentrional de la Republica Mexicana: Univ. Nacional Autónoma, Instituto de geologia, Cartas geólógicas y mineras de le República Mexicana, No. 3.
13. King, R. E., 1939, Geologic reconnaissance in northern Sierra Madre Occidental of Mexico: Geol. Soc. America Bull., v. 50, p. 1625–1722.
14. Koch, G. S., 1956, The Frisco Mine, Chihuahua, Mexico: Econ. Geol., v. 51, p. 1–40.
15. ——, 1956, Las Minas Frisco y Clarines: Congr. Geol. Intern., Excursiones A-2 y A-5, Vigesima Seccion, Mexico, p. 109–118.
16. ——, 1956, Geologia del area vecina a San Francisco del Oro y Santa Barbara: Congr. Geol. Intern., Excursiones A-2 y A-5, Vigesima Seccion, Mexico, p. 97–100.
17. Lindgren, Waldemar, 1933, Mineral deposits: New York, McGraw-Hill.
18. Lowther, G. K., and Bell, E. B., 1956, Geologia de la Mina Esmeralda: Congr. Geol. Intern., Excursiones A-2 y A-5, Vigesima Seccion, Mexico, p. 93–96.
19. ——, and Marlow, G. C., 1956, Geologia del area de Parral: Congr. Geol. Intern, Excursiones A-2 y A-5, Vigesima Seccion, Mexico, p. 79–88.
20. Marlow, G. C., and Smith, J. M., 1956, Geologia de la Mina La Preita: Congr. Geol. Intern., Excursiones A-2 y A-5, Vigesima Seccion, Mexico, p. 89–91.
21. Newhouse, W. H., 1942, Structural features associated with the ore deposits: Ore deposits as related to structural features, Princeton Univ. Press, p. 9–53.
22. Ordóñez, Ezequiel, 1897, Itinerarioa geológicos: in Bosquejo geológico de Mexico, Inst. geol. México, Bol. 4, 5, 6, p. 75–77, 259.
23. Schmitt, Harrison, 1928, Geologic notes on the Santa Barbara area in the Parral district of Chihuahua, Mexico: Eng. and Min. Jour., v. 126, p. 407–411.
24. ——, 1931, Geology of the Parral area of the Parral district, Chihuahua, Mexico: Am. Inst. Min. Eng. Trans., General volume, 1931, p. 268–290.
25. Spurr, J. E., and Garrey, G. H., 1908, Ore deposits of the Velardeña district, Mexico: Econ. Geol., v. 3, p. 688–725.
26. Smith, F. W., 1910, Conditions at the Palmilla mine, Parral, Mexico: Eng. and Min. Jour., v. 90, p. 259–262.
27. Stose, G. W., editor, 1946, Geologic map of North America, Scale: 1:5,000,000: New York, Geol. Soc. America.
28. Waitz, Paul, 1906, Esquisse géologique et pétrographique des environs de Parral: 10th Intern. Geol. Cong., Guide des Escursions, fasc. 21.
29. Weed, W. H., 1902, Notes on a section across the Sierra Madre Occidental of Chihuahua and Sinaloa, Mexico: Am. Inst. Min. Eng. Trans., v. 32, p. 444–458.
30. Weeks, L. G., 1957, Origin of carbonate concretions in shales, Magdalena Valley, Colombia: Geol. Soc. America Bull., v. 68, p. 95–102.
31. Wilson, I. F., and Rocha, V. S., 1948, Manganese deposits of the Talamantes district near Parral, Chihuahua, Mexico: U. S. Geol. Survey Bull. 954-E, p. 181–208.

Economic Geology
Vol. 53, 1958, pp. 1038–1049

DISCUSSIONS

SUPERGENE COPPER URANIUM DEPOSITS, NOVA SCOTIA

Sir: J. J. Brummer, in Supergene Copper Uranium Deposits in Northern Nova Scotia,[1] describes occurrences that are in many respects similar to ones presently under study in Pennsylvania. A preliminary descriptive report has been published by the Pennsylvania Geologic Survey.[2] A more complete and detailed study is now in preparation with plans for publication sometime in 1959. The work is being done at Columbia University with the support of the Pennsylvania Geologic Survey.

The Devonian Catskill formation is the host for more than forty presently uneconomic prospects located in the north central portion of the state. The Catskill formation is similar in lithologic characteristics to the Pictou formation (of Pennsylvanian age) which is the host for the prospects described by Brummer. Both are essentially red-bed formations that contain numerous gray to green cross-bedded channel deposits rich in carbonaceous material. Both tend to be micaceous and clay galls are abundant, the Catskill being considerably less arkosic than the Pictou.

As in Nova Scotia these "redbed occurrences" have long been known. The majority of the prospects are the sites of copper workings dating from the latter half of the nineteenth century. The mineralization is also associated with carbonaceous material in the form of individual plant fragments or thin seams and stringers of coaly matter. The distribution of the radioactivity is spotty but locally individual specimens giving analyses up to 0.83% U_3O_8 equivalent have been found, as opposed to a reported maximum of 0.39% U_3O_8 equivalent in Nova Scotia. Secondary uranium minerals such as metazeunerite ($Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$) and uranospinite ($Ca(UO_2)_2(AsO_4)_2 \cdot 8-12H_2O$) have been recognized from several localities but much of the radioactivity emanates from carbonaceous material in which no uranium minerals have been identified, as is the case reported by Brummer. The uranium may be present as a very finely disseminated oxide within the carbonaceous material or as an urano-organic compound, or in the ionic form due to solution by ground waters and adsorption on carbon. Sulfides are also present in much the same relationship as in Nova Scotia and it is assumed that they have a common origin with the uranium as indicated on p. 319 of Brummer's article.

However, certain additional features are noted in many of the Pennsyl-

[1] Econ. Geol., v. 53, no. 3, pp. 309–324, 1958.
[2] J. F. McCauley, Preliminary Report on the Sedimentary Uranium Occurrences in the State of Pennsylvania, Progress Report 152, 1957.

vania occurrences that lead to a genetic viewpoint quite different from that proposed by Brummer. Brummer recognized pyrite and minor amounts of bornite and chalcopyrite which he considered to be syngenetic in origin. The more abundant chalcocite and covellite were considered to be supergene.

In many of the Pennsylvania occurrences a more complex and diagnostic suite of sulfides is present. Pyrite, chalcopyrite, bornite, galena, digenite, chalcocite, and covellite are the predominant sulfides along with barite gangue and secondary malachite and azurite at the surface. The sulfides fill cracks and replace or fill plant cell structures in a manner like that shown in the plates of Brummer's article on pp. 314–315. Despite the presence of chalcocite, these occurrences are considered to be unquestionably primary at least insofar as the chalcopyrite, bornite, galena, and barite are concerned, and have not been extensively reworked by ground water, as the chalcocite is in relatively minor quantities. The pyrite is the earliest sulfide, being followed by relatively abundant amounts of bornite and chalcopyrite. The bornite contains oriented laths of chalcopyrite in the 111 direction, which exhibit all the classical exsolution features. These are readily seen at high magnifications, but barely visible when magnified 100 times under the reflecting microscope. Heating of the specimens for two weeks at 180° C promoted exsolution because of the increased diffusion rate at the higher temperature. The exsolution laths were then readily visible at one hundred times magnification. Figures 1 and 2 show different areas of the same polished surface with the exsolution laths both before and after heating. Solid solution of parts of a polished surface was achieved by heating for five days at 400° C after which the specimen was quenched. This temperature is excessive for a minimum temperature of formation but was used to reduce the time factor. Experiments are continuing in the hope that specimens can be rehomogenized between 200–300° C by heating over longer periods of time.

Therefore, present evidence definitely points to an elevated temperature of formation, at least in excess of 180° C so that a supergene or syngenetic origin for the primary sulfides is untenable. Galena, also a primary sulfide, is present in major quantities at one locality and in minor amounts at several others. It is later than the bornite-chalcopyrite. Overlapping with the galena is a bluish chalcocite-like mineral that X-ray Powder photographs revealed to be digenite. Overlapping this but generally later is barite, which fills fractures in the pre-existing minerals and in the carbonaceous material. It contains blebs of chalcopyrite apparently later than the barite and definitely later than the other primary sulfides; these blebs represent a second generation of chalcopyrite mineralization. Last in the sequence are the secondary or supergene sufides chalcocite and covellite. Certain occurrences contain only these two minerals along with early pyrite. If these were the only type observed a syngenetic-supergene origin would be tenable. However, because many others exhibit exsolution, an origin from moderately hot solutions is required. In the pyrite-chalcocite-covellite association, the two copper sulfides are ascribed to reworking of the primary occurrences by meteoric waters with the pyrite being the only unreplaced primary sulfide.

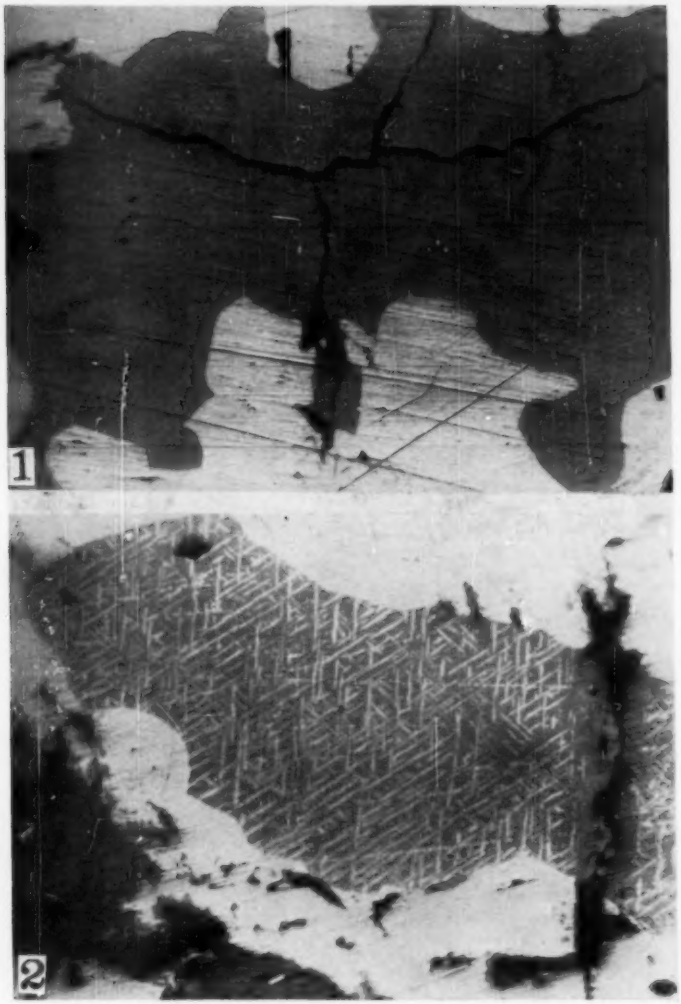


FIG. 1. Bornite (dark gray) showing faint chalcopyrite exsolution laths, surrounded by galena (light gray). The laths, faintly visible, are oriented as in Figure 2, below. (100 ×)

FIG. 2. Same specimen (different area) after heating for 2 weeks at 180° C. Exsolution laths are larger; easily visible at same magnification (100 ×). Galena (light gray) and carbonaceous material (black).

The general paragenetic sequence might be summarized as:

pyrite
bornite
chalcopyrite
galena
digenite
barite
chalcopyrite
chalcocite
covellite

The time of emplacement of the primary sulfides is considered to be after the coalification process had begun. The coaly material has well developed joints and cleats as is common in bituminous coals. Proximate analysis of the material indicates that it compares closely with low-volatile bituminous coals. The sulfides fill, and in some cases replace along these joints or cleats. They could have developed only after the material had advanced in the process of coalification. Brummer, however, states (p. 316) "that it [pyrite] replaces the plant cells of the woody material indicates that the replacement took place before carbonization of the material." Much of the carbonaceous material as shown in Brummer's photos and as seen in the sections of the Pennsylvania occurrences show no cell textures at all. On the other hand certain bands or stringers within the sections show well preserved cell textures, in many cases filled with sulfides. These areas are interpreted as fusain or mineral charcoal. Although the exact origin of fusain still is in doubt, it is known to preserve plant cell structures throughout the coalification process, as quoted in many texts and accepted by most coal petrologists. Thus the fact that cell structures are preserved is not evidence that filling of the cells took place before coalification. On the contrary, the filling of joints and cleats by sulfides points to the fact that the mineralization took place sometime after the beginning of coalification. Thus the possibility of the primary sulfides being syngenetic is once again precluded.

Stratigraphic studies in the area of the majority of the occurrences point to a broad threefold subdivision of the Catskill formation. An upper zone about 400 feet thick contains mostly gray to green sandy channel deposits with minor interbedded red units. Carbonaceous material is abundant but the only mineralization is a minor amount of non cupiferous, non-uraniferous pyrite in the form of nodules. These are in a thin black shale lens and are considered to be syngenetic or diagenetic in origin. Below this upper zone is a sequence 1,000 feet thick of predominantly red shale and mudstone with a few thin gray to green channel deposits, and no reported mineralization. The lowest zone, about 800 feet thick, is transitional into the underlying marine Devonian rocks. It consists of a complex overlapping network of gray to green channel deposits and red mudstones and shales. Carbonaceous material is abundant in the gray units and mineralization is confined to these thin seams and stringers.

It is believed that this distribution of the copper-uranium in the lowermost horizon suggests, but does not prove, an origin from rising solutions. If the mineralization originated from descending solutions or was syngenetic, it is hard to explain why the equally favorable upper zone is barren except for a few pyrite nodules, whereas the lowermost zone is mineralized rather extensively. It is easier to explain this distribution on the basis of rising moderately hot solutions that moved considerable distances laterally beneath the unfavorable and impermeable middle shale barrier. After depositing a suite of minerals that might be considered typical of epithermal ore deposits, the solutions were exhausted or simply were not able to pass through the shale barrier to mineralize the carbonaceous upper zone.

The question as to whether the metals in these solutions were derived ultimately from some deep magmatic source or whether they were derived by a process of regeneration from the weathering of other sediments or igneous rocks cannot be answered at this time. A study of the sulfur and lead isotope ratios may give the answer. However, it does appear that no matter what the ultimate source, the emplacement of significant amounts of copper, uranium, iron, and some lead took place through the action of solutions which for all practical purposes can be termed "hydrothermal." This is not to deny the action of meteoric waters in the reworking of these occurrences. Some have been so altered as to present an almost wholly supergene aspect. The writer would like to suggest that the occurrences reported by Brummer are in this advanced stage of reworking so that the primary characteristics that might have indicated a "hydrothermal" origin were either destroyed or obscured.

This discussion is published with the permission of the State Geologist, Pennsylvania Topographic and Geologic Survey.

JOHN F. MCCAULEY

PENNSYLVANIA GEOLOGIC SURVEY, HARRISBURG, AND
ORE GENESIS LABORATORY, COLUMBIA UNIVERSITY, NEW YORK
July 9, 1958

THE CLASSIFICATION OF METALLIFEROUS PROVINCES AND DEPOSITS

Sir: I should like to discuss this paper by C. J. Sullivan (1) briefly. I shall bear in mind the author's statement that the classification is "suggested" and "tentative" and base my major criticisms primarily on disagreement with what are presented as its supporting facts.

The Table of Contents, p. 3, defines it as "A suggested method of classifying ore deposits for mining men which substitutes the prospectors' terminology for the more theoretical terms of thermal classification." The descriptive title, top of p. 26 and 27, is "Ore Classification Using Prospectors' Terms." Whether or not the author is responsible for the specific wording quoted above, it is entirely consistent with the language and purport of the article itself.

In his opening paragraph Mr. Sullivan reminds us that classifications found "in most textbooks" of recent date are based upon "assumed temperatures of deposition" for which descriptive terms such as "hypothermal, mesothermal and leptothermal" are used. Such terms 1. do "not convey much about the value of the deposit" nor 2. "suggest where similar ores may be found," and furthermore, 3. are "little used by today's prospectors."

Instead, Mr. Sullivan proposes to present a classification based upon "field associations," using terms which "immediately convey a practical meaning." The implication is that this classification would avoid the alleged shortcomings of the classifications of modern textbooks and would, in contrast, 1. indicate more accurately the value of deposits, 2. serve as a guide in the discovery of similar ores, and 3. employ terminology more familiar to the practical mining men and today's prospectors.

To discuss the adequacy of the classification as a substitute or alternative for those of the "textbooks" or for the accomplishment of the purposes set forth, with any degree of satisfaction to geologists, would require the review of the literature of economic geology concerning the districts cited in his thesis, going back over the years. I must be satisfied in dealing with a few instances only wherein the Sullivan tabulation seems to me to be inaccurate, inconsistent, or to fall short of the objectives mentioned.

In the first place, let us examine the names of the groups and subgroups of the classification. Most of these titles include two features, one an assumed source of metal, the other an assumed genetic process. The genetic processes are indicated in these titles by such words and phrases as "Ores Derived From—Ores Concentrated During Granitization—Ores Due to Granitization—Ores Concentrated by Granitization—Syngenetic Ores—Metal Accumulations Re-concentrated Thermally," etc.

Not only in these titles but in the more detailed specifications of characteristics of the several categories are many terms of genetic significance which to geologists convey much concerning temperatures of formations of the different classes as proposed. As examples, the following phrases are found: reconcentrated during granitization, reconcentrated by meteoric waters, reconcentrated thermally, concentration during cooling, or during folding and metamorphism, sulphides expelled from consolidating magma, ore associated with contacts (igneous) or with "digestion" or separated during cooling of magmas, or during recrystallization or reheating, etc.

Thus, while in his second paragraph Sullivan implies the presentation of a simple and "practical" sub-division of ore deposits based upon field occurrences (he cites "native copper in basalts, copper-nickel ores associated with basic igneous rocks, asbestos in serpentine, red-bed copper, etc.") as a substitute for the "theoretical" thermal classification of the modern textbooks, he emerges with a classification in which such homely terms of field occurrence are in the main entangled with and subordinated to terms of direct genetic and, in most instances, of the thermal significance which he disparages when used in the textbooks.

In his column, "Possible Origin," many of his choices are contrary to the preferences of students in the particular fields. Every economic geologist

will recognize examples wherein his choice of origin would be questioned. These include the copper uranium ores of southwestern United States, lead and zinc ores of central United States, Michigan copper and Canadian gold, to name some.

I doubt that "mining men" with the data of field associations as given in this table would have any advantage either in appraising "the value of a deposit" or in deciding "where similar ores may be found." On the contrary, they might very well be misled. For instance, the outstanding process which has made copper ore out of most disseminations in porphyry is that of secondary supergene enrichment. This involves oxidation with leaching of copper near the surface, by meteoric waters which then carry it downward to be reprecipitated below the water level, forming the enriched zone constituting the orebody.

Mr. Sullivan does not in any way recognize the operation of this process. Instead of concentration by supergene enrichment being responsible for the orebody at Ray, for instance, the caption on the photograph indicates that it is more reasonable to regard it as "simply a copper ore concentrated by the granitization of gabbro-diabase-type rocks." Since this classification purports to replace others as a guide in exploration, we are to understand that our mining man in the search for another Ray would look for "granitization of gabbro-diabase-type rocks," rather than follow the more orthodox procedure of seeking for and analyzing the significance of gossans and leached croppings.

It has already been pointed out that "Field Association," although said to constitute the basis of the classification, is really overshadowed by a grouping of genetic (and thermal) significance. However, field association is indicated in a subordinate manner in the column "Rock Environment." Here, if anywhere, one should find nothing to dispute (once such fundamentals as rock identification are agreed upon). It should be a simple adherence to the facts of what it is said to be, viz.; field associations or rock environment. But even in this elementary presentation we are bewildered.

Consider the "Rock Environment" of the Michigan native copper deposits. According to Sullivan, it is "Basalts considerably folded and altered, but no granite." My discussion of the origin of these deposits has been presented in the past (2) and will probably be presented again in the future, but this, of course, is not the occasion. Suffice to point out that instead of "considerably" folded, the degree would be more acceptably designated as "gently" or, at the most, "moderately" folded. Specifically, the largest and richest orebody mined in the district to date is the one which occurs in the Calumet Conglomerate. Here the dip of the conglomerate is only 38 degrees and it becomes perceptibly less in depth down the limb of the Lake Superior syncline within the mine itself. Here also, even mild cross-folding is lacking.

As for the basalts of the district being "considerably altered," they are, on the contrary, commonly described by such terms as "surprisingly fresh." Even where intruded by the Mt. Bohemia "syenodiorite" and granite, the alteration, except within a few feet of the contact, is described as only very local and slight (3).

As for the presence of "no granite," it is recognized, on the contrary, that

there is a great igneous complex of Late Keweenawan age intruding these basalts and dipping with the syncline toward Lake Superior. A major part of this complex is a rock consisting predominantly of quartz and feldspar, commonly containing 65 to 75 percent silica and whose surface outcropping covers an area of over 200 square miles in Minnesota alone. The complex has been thoroughly studied by Grout, who calls this quartz feldspar phase "granite" (4), a name likewise accepted in the latest U. S. Geological Survey treatment of the Lake Superior region as a whole (5).

While the outcrop of this complex around the upturned eroded edges of the syncline is largest by far in Minnesota, its constituent rocks along with intrusive quartz porphyry or rhyolite of similar age and composition occur also intruding the same basaltic rocks of the copper-bearing series on the south limb of the syncline in Wisconsin and Michigan. The conspicuous example in the copper district is at Mt. Bohemia. Here the intrusive has a quartz feldspar phase (as in Minnesota) which commonly has copper sulfides in miarolitic cavities. The intruded rocks nearby carry spotty chalcocite deposits, an association which has attracted explorers for over a century. The more basic phase of this same intrusive in Minnesota has recently been found to carry disseminated copper-nickel mineralization (albeit low grade perhaps) near its base throughout a width of well over a hundred feet and over a length of 30 miles. (6)

Therefore, the implication that there is no igneous body including granite intruding the rocks of the Michigan Copper District, competent to furnish hydrothermal copper-bearing solutions to the intruded rocks is definitely not in accord with the facts. A huge intrusive over 150 miles in length dips with the Keweenawan basalts toward the trough of the syncline, reappearing in the Michigan Copper District on the south limb. Therefore it is difficult to believe that the ore-bearing beds of the Michigan Keweenawan did not tap this potential source of copper in depth. Why then call upon an involved process of leaching of the minute copper content of the earth's crust (.01 percent) for method and sources. In fact, the copper content of the Lake Superior Keweenawan basalts called upon as a source for the ores is, according to existent estimates, considerably lower than that of similar rocks of the earth's crust in other regions. (7)

To repeat in summary, I wish to emphasize that the statement of field associations of the Michigan copper deposits as given in Sullivan's column, "Rock Environment," is *not* in accord with the facts on all three counts, viz.; the basalts are *not* considerably folded, they are *not* considerably altered, and there *is* granite intruding them. Other examples from the table might be selected by specialists in other fields for criticism.

It remains to comment upon the terminology used. After his critical remarks concerning textbook classifications based upon temperatures, he says "such terminology is little used by today's prospectors." One might deduce that former generations of prospectors did use such terms as "lepto-thermal," etc., and that modern prospectors had graduated into a familiarity with the terminology to be employed in the Sullivan classification.

In any event, let us see what terms are used by today's prospectors. The "mining men" who might be led to hope that here at last was to be a disclosure of hidden but simple meaning behind the jargon of the geologist, which would enable them to "do it themselves," are due for a shock. They are confronted with granitization, evaporites, low-grade metamorphism, structural foci, porphyritization, re-mobilized, paragneiss, skarn, euxenic, etc., language which any textbook writer would be proud to use. Two Ph.D.'s in economic geology admitted having to refer to textbooks to refresh themselves as to the meaning of some of the terms. Our mining man will therefore be fortunate if he can even read the classification intelligently, much less use it to arrive at the value of a deposit, or to seek for another like it.

THOMAS M. BRODERICK

CALUMET, MICHIGAN,
July 29, 1958

REFERENCES

1. Sullivan, C. J., 1958, The classification of metalliferous provinces and deposits: Eng. & Min. Jour. v. 159, no. 6a, p. 26–28.
2. Broderick, T. M., Hohl, C. D., and Eidemiller, H. N., 1946, Recent contributions to the geology of the Michigan Copper District: ECON. GEOL., v. 41, p. 675–725.
——, 1952, The origin of Michigan copper deposits: ECON. GEOL., v. 47, p. 215–219.
3. Cornwall, H. R., 1954, Bedrock geology of the Delaware quadrangle, Michigan: U. S. Geol. Survey Quadrangle Map G Q51.
Butler, B. S., Burbank, W. S., et al., 1929, The copper deposits of Michigan: U. S. Geol. Survey Prof. Paper 144, p..34.
4. Grout, Frank F., 1918, A type of igneous differentiation: Jour. Geology, v. 26, p. 626–658.
5. Leith, C. K., Lund, Richard J., and Leith, Andrew, 1935, Pre-Cambrian rocks of the Lake Superior district: U. S. Geol. Survey Prof. Paper 184, Plate 1.
6. Anderson, Gerald E., 1956, Copper-nickel in the Duluth Gabbro near Ely, Minn., Pre-Cambrian of N.E. Minn.: Guide book Series Geol. Soc. America, p. 91–95.
7. Sandell, Ernest B., and Goldich, Samuel S., 1943, The rarer metallic constituents of some American igneous rocks: Jour. Geology, v. 51, p. 167–189.

MINERALOGY OF PHOSPHATE OOLITES

Sir: A recent article in ECONOMIC GEOLOGY (Vol. 53, p. 110, 111) criticized the careless use of terms describing the chief phosphate component of certain phosphorites in Florida. A suggestion was made to be more specific by calling the phosphorite mineral "francolite" instead of "fluorapatite." Based upon the work that we have done on the mineralogy of the oolites from the Gay mine, Fort Hall, Idaho, we seem justified in using the name "fluorapatite." If one cares to be more specific the term "carbonatian-fluorapatite" or "carbonate-fluorapatite" describes the mineral completely. Reasons for this position are given herein.

Apatite Series.—This is an isomorphous series having the general formulation $Ca_5 (P_{1-x}C_xO_{4-x}OH_x)_3$ (F, Cl, OH). Apparently the substitution of (CO_3OH) groups for (PO_4) groups is possible. The series may be regarded as having the following end members: fluorapatite, $Ca_5(PO_4)_3F$, chlorapatite, $Ca_5(PO_4)_3$ Cl, hydroxylapatite, $Ca_5(PO_4)_3$ OH, and carbonate-apatite, $Ca_{10}(PO_4)_6(CO)_2 \cdot H_2O$. Fluorapatite has about five variations

based upon slight changes from the idealized formula. Hydroxylapatite has about four such variations.

Apatite Mineral Names.—It appears logical that with such variations possible in the apatite series, based upon ionic substitutions, there is a practical limit to the number of mineral names one can give to each variation. These compositional variations may involve solid solutions of small amounts of Al, Cr, Fe, Mn, Sr, Si, S, and Na.

Apatite minerals within a single deposit are likely to have slightly different chemical compositions in different parts of the deposit. At the Gay mine we believe the main variation may be due to the ionic substitution of carbonate groups for phosphate groups. The average chemical composition is close to the fluorapatite end member. It seems more realistic to say the mineral is a carbonatian variety of fluorapatite than to assign to it a separate mineral name "francolite." The term "francolite" implies no chemical or crystallogical description as does "carbonatian-fluorapatite." The term "collophane" is a hold-over from years ago when it was believed that the oolites had no crystalline structure. X-ray powder patterns have disproven that concept. "Collophane" can be used as a generic designation for cryptocrystalline types of apatite, but should not be regarded as a mineral name.

"Pellets" vs. "Oolites".—Most phosphorites contain grains of spherical collophane that have been termed "oolites," "pellets," and "nodules" by various authors. The distinction between these types is obscure, although some persons have stated that oolites should show a concentric structure. This distinction is not supported by either Webster's "Unabridged Dictionary" or Rice's "Dictionary of Geological Terms." The term "oolite" is derived from two Greek words which mean "Egg-stone." In any case, some of the spherical collophane grains from Fort Hall do have concentric features. The term "oolite" is slightly preferred to "pellets" because of prior usage in geologic literature.

Fort Hall Phosphate Mineral.—X-ray powder patterns prove that the Fort Hall mineral has the crystalline structure of fluorapatite. Pure fluorapatite of the composition $Ca_5(PO_4)_3F$ contains 42.2% P_2O_5, whereas the highest P_2O_5 content of phosphate oolites from Idaho is about 39% P_2O_5. Most oolites from Fort Hall contain about 36% P_2O_5. The minimum CO_2 content is from one to three percent. Fluorine is usually slightly above three percent. The ignition loss amounts to about four or five percent. A typical oolite may contain two percent CO_2, two percent hydrocarbon impurities, and about one percent OH.

For pure fluorapatite the theoretical ratio of CaO to P_2O_5 is 1.317. The minimum ratio for Fort Hall oolites is 1.40 to 1.42. This deficiency of phosphate in the oolites may be partly accounted for by the substitution of (CO_3OH) groups for (PO_4) group in the apatite lattice, as has been mentioned previously. Some oolites that have CaO to P_2O_5 ratios much above 1.42 have minute calcite inclusions in them, but there is much evidence that the pure phosphate mineral composing the oolite does have a CaO/P_2O_5 minimum value of about 1.40.

Chemical Analyses of Fort Hall Oolites.—

	Wt., %				
	Samples				
	1	2	3	4	5
P_2O_5	35.65	35.33	35.24	36.2	36.0
CaO	49.64	49.17	49.88	52.1	51.6
SiO_2	5.57	6.42	5.62	0.1	0.2
Al_2O_3	1.91	2.48	1.05	0.3	.5
F	3.04	3.15	3.00		
Ign. loss	5.80	4.95	6.13	4.8	4.9
CaO/P_2O_5	1.40	1.40	1.43	1.44	1.43
Fe_3O_4				0.4	0.3
Total assay	101.6	101.5	100.9	93.9	93.7
Less O = F	1.3	1.3	1.3		
Net	100.3	100.2	99.6		

Conclusions.—

1. The phosphate mineral of oolites from the Gay mine is carbonatian-fluorapatite.
2. "Collophane" should not be used as a mineral name, but can be used to describe cryptocrystalline types of apatite.
3. Names of minerals of the apatite series should be based upon the end members of that series. Names such as "francolite" and "dahllite" are not as appropriate as "carbonatian-fluorapatite" and "carbonate-apatite."
4. When the exact composition of an apatite mineral is unknown, or when speaking of a mineral deposit in general terms, it is acceptable to use the names of the probable end members, such as fluorapatite or hydroxylapatite, etc., without specifying which variety is present.
5. The number of possible variations from the general apatite formula is too large to give each variety a proper name.

G. W. MARTIN

FOOD MACHINERY AND CHEMICAL CORP.,
MINERAL DEVELOPMENT DEPT.,
POCATELLO, IDAHO,
Sept. 14, 1958

URANIUM IN ANCIENT CONGLOMERATES

Sir: Shed of its impertinences, a recent letter contributed to ECONOMIC GEOLOGY (v. 53, p. 620–621, 1958) by Professor Ramdohr consists entirely of accusations that I have mistranslated and misquoted him. For the record it should therefore be stated that, lest my own interpretation of his subjective monograph be accused of bias, I had an independent translation prepared by

a Government agency early in 1955, the identity of the translator being unknown to me. This English text, which has been on public file in the library of the Geological Survey of Great Britain for more than three years, is the sole source of my quotations. Collation of the German and English versions shows that imputations of misquotation are quite unfounded. It is to be hoped that the "almost word-for-word translation into English" shortly to be published by Ramdohr himself will exhibit equal integrity of purpose.

C. F. DAVIDSON

UNIVERSITY OF ST. ANDREWS,
SCOTLAND,
Sept. 17, 1958

Economic Geology
Vol. 53, 1958, pp. 1050–1060

REVIEWS

Genetic Relation of Mineralization to Granitoid Intrusions. By KH. M. ABDULLAEV. Pp. 294; figs. 68; tables 33. Gosgeoltekhizdat, Moscow, 1954. 2nd edition. Price, roubles 11.60. Circulation, 8,000 copies. (Only in Russian.)

The late D. S. Belyankin, in the preface, gives credit to the author for presenting persuasive facts illustrating the great importance of the medium on the process of ore genesis, stressing, however, that this problem can not be completely solved at the present time, especially by one person.

The 1st chapter of the book is dedicated to the history of the study of ore genesis, the 2nd and 3d—to the problems of the theory of ore genesis and petrology, and chapters 4 to 8—to the genetic relation of postmagmatic mineralization to intrusions. In chapters 9 and 10, the author discusses the principles of classification of ore deposits based on the hypothesis of metallogenetic specialization of magma. Reference is made to the practical value of this hypothesis relative to prospecting and exploration. The author does not consider the relation of ore deposits to basic intrusions and dikes, and the relation of small intrusions to folding.

Speaking about the "development of the Soviet theory of metallogeny under conditions of bitter struggle against the relics of the bourgeois theories of ore genesis," Abdullaev postulates that the processes of formation of postmagmatic deposits, metallogenetic provinces, and their relation to magmatic processes, have to be considered from the point of view of the geological history of a particular province and of the mutual dependence of all geological processes that occurred in the area. The concentration of metals contained in magma in the form of ore deposits occurs only under conditions of a favorable reaction of magma with the geological medium.

The author studies the contribution of granitoids to the formation of postmagmatic deposits (all types of magma are considered as potential sources of postmagmatic ore deposits), the geochemical relation of postmagmatic solutions to the composition of magmatic mother rocks, the importance of the processes of assimilation and hybridism to the petrochemical variation of granitoids, and the geochemical specialization of postmagmatic solutions (the author assumes the possibility of assimilative enrichment of granitic magma with metals derived from country rock), the importance of tectonic factors for the formation of postmagmatic deposits, the genetic relation between the deposits and intrusions, the principles of classification of postmagmatic deposits, and the metallogenetic importance of the problem of mineralization related to magmatic processes.

Abdullaev emphasizes that the metallogeny of postmagmatic processes should be based on recognition of the affiliation of ore deposits with concrete intrusions. Facts about the influence of the processes of assimilation and hybridism of the composition and character of postmagmatic solutions in some regions of Central Asia are used to support the conception of assimilative specialization of granitic magma and of postmagmatic solutions.

Criticizing Locke and Billingsley, the author develops the following theses: (1) Conditions for the evolution of magmatic processes and postmagmatic mineralization in labile zones depend not only on fractures through which magma intrudes but also on the development of folded structures in geosynclinal regions. The formation of folds is connected with intrusions of acid magma which assimilates and induces the metamorphism of folded formations. (2) The value of structural factors is not equal in different genetic types of deposits. The evolution of the mineralizing solutions proceeds not only in space, as the distance from the intrusions increases, but also in time. The role of fractures changes in a similar manner.

Existing genetic classifications of postmagmatic deposits are based on the orthodox magmatic theory by Lingren, Emmons, and Buddington. Abdullaev considers these classifications as "narrow physico-chemical schemes" in which the main geological factors are not taken into consideration, and therefore, do not reflect the genetic relation of postmagmatic deposits to intrusions.

The acid intrusions and affiliated ore formations differ from each other because of the character of the media within which they developed. These media can be alumosiliceous, ferro-magnesian, or calcareous. In the first case the composition of country rock is similar to that of the magma, in the second case the composition of magma greatly differs from the composition of the country rock. An attempt is made to outline two genetic rows of postmagmatic deposits related to granitic magma: (1) Deposits with alumosiliceous contamination or without contamination, related to acid intrusions (alaskites, granites); this row is represented by pegmatites and quartz greisen formations; (2) Deposits with calcareous and mixed contamination, related to intrusions of an increased basicity; this row is mainly represented by skarns and quartz-sulfide deposits.

Speaking about the genetic relation of mineralization to intrusions, Abdullaev postulates that American geologists overestimate the importance of deep seated zones of the earth's crust, while mineralizing solutions are formed in the upper 10–15 km of the crust under hypabyssal conditions. Referring to the late Obruchev, who discussed in 1942 the influence of country rock on the character of mineralization, the author assumes that the geological medium influences not only the geochemical evolution of mineralizing solutions, but sometimes induces the formation of these solutions.

The formation of granitic magma at a definite stage of geological evolution of a region is caused mainly by thermal energy generated by radioactive decay. The author denies the existence of liquid magma since the formation of the earth's globe, and condemns this concept as metaphysical. The differentiation of magma proceeds within the magmatic basin. All petrochemical types of magma are potentially metalliferous. This statement is supported by data on 500 spectral analyses of granites made in 1951 by Shevchenko. These analyses indicate no difference in the frequency of occurrence of metals in granite with which a certain mineralization is connected, and the so-called "sterile" granites. Magmatic rocks may differ in content of metallic compounds, and favorable conditions are necessary for the concentration of these metals in the form of deposits.

Magmatic processes are associated only with vertical movements of the earth's crust in epirogenic and orogenic regions. The process of evolution of a geosyncline is subdivided into two subcycles: (1) Uniform accumulation of sediments of flysh type, corresponding to a long period of subsidence, and (2) Complex accumulation of sediments simultaneously with folding. During the first subcycle sediments could form similar in composition to the granites. During fast pene-

tration of magma into the upper horizons there is no typical contamination. The development of a geosynclinal system is characterized by consecutive intrusion of basic and acid magma. Regional geological features, illustrating the genetic relation of mineralization to intrusions are represented by the facial character of intrusions (hypabyssal, medium, and abyssal). Postmagmatic deposits belong also to respective facies. The geochemical consanguinity of postmagmatic solutions with the intrusions decreases as the distance from the source increases.

The role of regional fractures in the formation of ore deposits is overestimated by American geologists. Abdullaev distinguishes two types of ore-bearing formations: (1) High-temperature ore deposits (skarns, pegmatites, and hydrothermal deposits within the intrusives and near the intrusives). These ore formations are associated with major regional folded structures which are sometimes accompanied by major fractures. In this case the ore-bearing belt is related to the linear arrangement of intrusions. (2) Low-temperature hydrothermal deposits, remote from the intrusives. This type of deposit is associated with major fractures, commonly located between the abutting platforms. The role of channels in the formation of skarns is usually overestimated. High solutions are probably able to penetrate through pores and fine fractures, resulting in domination of the metasomatic mineralization. However, the importance of major fractures is prominent in propagation of low-temperature postmagmatic solutions, and deposition of minerals in open space. Folded structures, in general, and anticlinoria in particular, are favorable sites for location of intrusives and formation of postmagmatic deposits. Examples of structural elements determining the morphological features of high-temperature hydrothermal deposits from Central Asia illustrate this concept.

Discussing the assimilative specialization of magma as an evidence of the genetic relation of postmagmatic deposits to the intrusives, Abdullaev describes the features of the process of assimilation in the Tien Shan Mountains: (1) Occurrence of granites and alaskites within alumosiliceous rocks, (2) Presence of xenoliths, and (3) Zoning of the intrusion, depending on the composition of the country rocks. The composition of the intrusion changes with alteration in the composition of the country rock. Unstable tectonic development is a positive factor in the progress of digestion of country rock by magma. Sedimentary rocks recrystallized under the influence of early phases of the magmatic process, are subjected in lesser degree to assimilation than unaltered rocks. Therefore, intrusions of later phases are represented in most cases by acid and less contaminated rocks. However, the presence of volatiles may intensify assimilation. During assimilation of flysh formations the postmagmatic solutions may be enriched in boron, vanadium, and beryllium. Pegmatites, greisens, beresites, sericitization, alkaline metasomatose and silicification, quartz veins with wolframite, cassiterite, molybdenite, and other sulfides, are connected with intrusions contaminated with alumosiliceous material. Skarns, and probably hydrothermal veins with abundant carbonates, sulfates, and sulfides of base metals are connected with intrusions contaminated with calcareous and ferromagnesian material. The relation of the components of postmagmatic solutions is illustrated by facts on the behavior of iron, manganese, titanium, boron, tungsten, tin, and vanadium in sedimentary formations and intrusions. Country rocks react with circulating postmagmatic solutions not only as precipitants, but also as enrichers. Ore deposits may form as a result of such enrichment. The assimilative specialization of magma and postmagmatic solutions is illustrated by examples of skarn deposits in which the

presence of a large amount of magnetite excludes the possibility of accumulation of scheelite, and a concentration of scheelite excludes the concentration of wolframite. The migratory capability and concentration of elements in postmagmatic solutions depend on the character of assimilative evolution of magma.

Abdullaev discusses the paper by Sullivan on ore genesis and granitization (ECONOMIC GEOLOGY, 1948, n. 6; 1949, n. 9), considering it as scholastic, and the conception defended by the American author as metaphysical, for not having analyzed the various processes of interaction of magma with the geological medium in respect to evolution in time.

Differential zoning is another evidence of genetic relation of mineralization with intrusions. The theory of primary zoning by Emmons is constructed on the basis of the metaphysical concept of crystallization differentiation studied by Bowen. The zoning can not be represented in the form of a unique diagram covering all regions and all cases. A term "differential zoning" of deposits is proposed. Differential zoning is the result of differential development of postmagmatic solutions, different in time of formation and composition. Examples of the zoning of ore deposits illustrate the author's conception.

The problem of the relation between the mineralization and the intrusive body, according to Abdullaev, "has to be studied on the ground of the basic principle of dialectical materialism—the mutual relation and interdependence of the natural processes." The early solutions are produced by upper parts of the massif, the later ones by deeper horizons. It means that as the process of cooling of the intrusion progresses, the sources of postmagmatic solutions retreat to deeper horizons. The author lists 11 main criteria establishing the genetic relation of high temperature mineralization to intrusions.

Existing classifications of postmagmatic ore deposits are reviewed. The American systems of classification based on genetical and morphological principles are criticized from the point of view of dialectical materialism. The author develops his own genetic classification of hydrothermal deposits. This classification includes four types of deposits (deposits of the intrusive zone, deposits of the zone adjacent to the intrusive body, deposits located above the intrusive body, and deposits not directly associated with an intrusion). This classification includes the characteristics of typical formations, the geological location, the general environment of mineralization, relation to tectonics, form and size of the ore veins, mineral composition, structure and texture of ores, types of wall rock alteration, and typical deposits (mainly foreign). Abdullaev compares his classification with the classifications by Lindgren and Niggli.

The author suggests the study of the metallogeny of provinces, metallogeny of epochs, metallogeny of elements and processes of mineralization. Further studies of the genetic relations of postmagmatic deposits to intrusions require clarification of such problems as: (1) Existence of the differentiation of magma, (2) Relation of ore bodies to minor intrusions and dikes, (3) Location and character of the chamber where postmagmatic solutions are formed.

Betekhtin (1) makes acknowledgment to the author for the interesting facts on the skarn deposits of Central Asia. However, he thinks that the content of the book does not correspond directly to its title and contains a series of defects. The problem of the genetic relation of mineralization to intrusions is not thoroughly analyzed. The transportation of iron in oxygen-rich solutions during the process of suggested assimilation is not feasible. It is conjectural that magma could be considerably enriched with metals during the assimilation of country rocks.

Poyarkov (2) sharply criticizes Abdullaev in aiming at the interpretation of the geological facts recorded in Central Asia. He accuses the author of making an eclectical presentation of favorable analytical data supporting the advocated conclusions about the assimilative evolution of magma. Poyarkov disagrees with the author on the possibility of limiting certain facies of ore deposits only to skarns or to fractured zones. Batalov (4) says that Abdullaev did not consider the composite types of assimilation. The statement that all types of magma are potentially metalliferous is premature. The assimilation of country rocks by granitic magma is not the only factor determining the character of ore-bearing solutions. It is more probable that the character of these solutions changes because of the reaction with country rocks. A definite conclusion on the subject considered by Abdullaev may be attained after a study of the isotopic composition of the elements involved in the process of mineralization. This book is the result of a reaction against extreme theories on the subcrustal origin of ore-bearing solutions, without connection with intrusions. Babaev, Isamukhamedov (3), and Mezentseva (5) parry the criticism made by Poyarkov in respect to factual data on the geology of Asia and explain this criticism on the basis of a misunderstanding. The author himself is very tolerant of the critiques of his Russian colleagues.

Besides the original illustrations, some are taken from books and papers published by foreign authors, such as Emmons, Bateman, Ferguson, and others.

Dialectical materialism is the official philosophical doctrine in Soviet Union. Abdullaev obtrudes this ideology upon the concepts he advocates. Hypocritical accusation of western geologists of "mechanistic" or "idealistic" interpretation of theoretical problems was not in the tradition of the older generation of Russian scientists. Unfortunately, this trend has become prominent during the current decade and has acquired the features of fetishism. Sound criticism is possible only through unbiased analysis and thorough knowledge of the wide range of opponent hypotheses and theories. Such an approach, exclusively, serves best to benefit international scientific progress.

Despite a certain localism and some repetitions, the author deserves credit for putting on the agenda a complex of crucial problems of ore genesis and for throwing bridges across the gaps between the geological medium, intrusions, ore solutions, space, and time.

EUGENE A. ALEXANDROV

DEPARTMENT OF GEOLOGY,
COLUMBIA UNIVERSITY,
Sept. 1, 1958

REFERENCES

1. Betekhtin, A. G., 1955, Genetic relation of hydrothermal formations with intrusives. Fundamental problems in the study of magmatic ore deposits, p. 479–520. Academy of Sciences of the USSR, Moscow.
2. Poyarkov, V. E., 1955, Remarks on the book by Kh. M. Abdullaev "Genetic Relation of Mineralization to Granitoid Intrusions." Zapiski Vsesoyuznogo Mineralogicheskogo Obshchestva. 2nd ser., pt. 84, n. 1, p. 105–109.
3. Babaev, K. L., and Isamukhamedov, I. M., 1955, Remarks on the critique by V. E. Poyarkov of the book by Kh. M. Abdullaev. Same journal. 2nd ser., pt. 84, n. 4, p. 492–495.
4. Batalov, A. B., 1956, The book by Kh. M. Abdullaev. Same journal. 2nd ser., pt. 85, n. 1, p. 124–127.
5. Mezentseva, E. I., 1956, Some remarks respecting the review by V. E. Poyarkov of the book by Kh. M. Abdullaev. Same journal. 2nd ser. pt. 85, n. 1, p. 127–128.

The Geological Principles of Prospecting and Exploration of Ore Deposits. By V. I. SMIRNOV. Pp. 587; figs. 324; 2nd edition. Publishing House of the Moscow University, Moscow, 1957. Circulation, 8,000 copies. Price roubles 18.10. (Only in Russian.)

This manual, for the undergraduate students majoring in geology and geological exploration, has been written on the basis of lectures given by the author at the Moscow Institute of Gold and Base Metals, at the Faculty of Geology of the Moscow State University, and at the Moscow Institute of Geological Exploration.

The introduction reviews the history and development of the exploration of ore deposits in prerevolutionary Russia and in Soviet Union, the role of prospecting in the economy of the country, and stages of exploratory work.

The following subjects are discussed in this book:

Part I—Prospecting for ore deposits. Economic types of ferrous metal deposits, base metals, rare metals, radioactive metals, gold and platinum deposits. Geological prerequisites for prospecting based on study of igneous rocks, geological structures, stratigraphy, lithology, geomorphology, geochemistry, and hydrogeology. Principles of distribution of ore deposits and methods of survey and mapping of ore deposits. Guides for prospecting: rock alterations, distribution of heavy metals, abnormal content of metals in alluvium above the ore bodies and in mineralized springs, occurrences of boulders, outcrops of ore, plant indicators, and ancient pits and quarries. Prospecting for deposits covered with detritus, deposits covered with thick overburden, and prospecting for blind ore bodies. Evaluation of deposits according to outcrops.

Part II—Exploration of ore deposits. Techniques of exploration; selection between the exploratory pits and boreholes; systems of detailed exploration; location and spacing between the boreholes and pits. Geological exploration of an area. Fundamental principles of classification of ore reserves. Exploration of different types of ore deposits; examples of exploration of primary deposits; exploration of placers.

Part III—Sampling and geological documentation of deposits. Taking samples of ore for chemical analyses from underground workings in primary deposits, in placers, and in exploratory boreholes. Technological ore sampling. Reduction of bulk samples. Geological description of the deposit and the geological graphic methods.

Part IV—Calculation of ore reserves. Determination of basic parameters for calculation of reserves (thickness of the ore body, tonnage factor, grade of ore, area of the ore body, and correcting coefficients). Methods of calculating ore reserves. Presentation of data on calculated ore reserves for approval by the Territorial Commission for Reserves and by the State Commission for Reserves. Preparation of reports.

The bibliography covers some 350 references, and includes, besides the Russian, some American, German, and Polish sources.

This manual represents a rather compact course for the future mining engineer-geologists. However, in some of the Soviet schools, more extended programs include independent courses in prospecting, sampling, and in calculation of reserves. Methods of exploratory drilling and principles of mining engineering are the two separate courses that precede the courses in exploration. It is understood that some of the faculties or departments are specializing in exploration of nonmetallic minerals and caustobioliths.

EUGENE A. ALEXANDROV

DEPARTMENT OF GEOLOGY,
COLUMBIA UNIVERSITY,
Sept. 2, 1958

SIXTEEN REVIEWS OF RECENT RUSSIAN LITERATURE ON ECONOMIC GEOLOGY

The following books not hitherto noticed in ECONOMIC GEOLOGY, among others, have been received by the reviewer since mid-1957. Works of which publication has not yet been completed are denoted by an asterisk. Of the few periodical publications listed, most are new journals concerned with economic geology.

Geologicheskie poiski v Rossii. (Geological prospecting in Russia.) By F. D. BUBLEINIKOV. Pp. 251. Gosgeoltekhizdat, Moscow. 1956. 6r. 85k. (Paper covers.)

A brief history of the discovery of mineral deposits in Russia, ranging from the earliest times to the 19th century. There is a good bibliography of early literature.

Trudy Instituta Istorii Estestvozhnaniya i Tekhniki. (Transactions of the Institute for History of Natural Science and Technology.) Vol. 9. Pp. 352. Academy of Sciences, Moscow. 1957. 16r.

A collection of illustrated papers on the history of economic geology mining and metallurgy. Includes articles on the development of geological mapping in Russia (to 1881), on early geological studies in Azerbaidzhan, and 15 other topics, mainly technological.

*** Istoriya estestvoznaniya v Rossii.** (History of natural science in Russia.) Vol. I, part i, pp. 495, 30r. 60k.; vol. I, part ii, pp. 380, 24r. 65k. Academy of Sciences, Moscow, 1957.

These two books, the precursors of what will presumably be a multi-volume work, are issued by the "Institute for the History of Science and Technology" and comprise the writings of many authors. The first part of volume I covers the period to the end of the 18th century and the second part the first half of the 19th century. References to geology occupy some 32 pages in each. The works are handsomely illustrated and well produced, with a selected bibliography for each branch of science, but the treatment is not intensive. As in most Russian texts on the history of science Lomonosov is referred to *ad nauseam*—but Agricola, to whose works Lomonosov was greatly indebted, is only mentioned twice.

*** Izbrannye trudy.** (Selected works) of A. E. FERSMAN. Vol. III, pp. 798, 1955, 51r.; vol. IV, pp. 588, 1958, 36r. 70k. Academy of Sciences, Moscow.

These two memorial volumes of the more important works of Academician Fersman reprint most of his classic text on "Geochemistry" (1933–1939), of which the first two books make up the 1955 publication noted above and the third book forms the 1958 re-issue. The reprint of the fourth (final) book of "Geochemistry" has still to appear, as has also the re-issue of his great volume on granite pegmatites (1940). This standard edition of Fersman's works will therefore comprise at least six large volumes, of which numbers I and II appeared in 1952 and 1953 respectively.

Kristallografiya almaza. (Crystallography of the diamond.) By A. E. FERSMAN. Pp. 566, pls. 49. Academy of Sciences, Moscow. 1955. 24r. 40k.

A handsomely printed translation of the well-known monograph *Der Diamant* by Fersman and Victor Goldschmidt, published at Heidelberg in 1911, followed

by later articles on the Shah and Orlov diamonds. There seems no sound reason why Goldschmidt's name was omitted from the title page.

Spravochnik mer. (A reference book on measurement.) Pp. 224. Vneshtorgizdat, Moscow, 1956. 5r. 85k.

A useful and comprehensive dictionary of all the weights and measures of the world, tabulated under countries and also listed alphabetically, with metric equivalents.

Anglo-Russkii geologicheskii slovar'. (English-Russian geological dictionary.) By T. A. SOFIANO. Pp. 525. Gosgeoltekhizdat, Moscow, 1957. 17r. 90k.

Although this dictionary contains some 25,000 terms and phrases a good many words somewhat recently introduced into general geological English are lacking. The edition of 18,000 copies shows the extent of the Russian interest in western literature.

English for miners. By N. D. KUCHIN AND OTHERS. Pp. 508. Ugletekhizdat, Moscow, 1956. 7r. 55k.

There has been an edition of 10,000 copies of this well-produced and inexpensive text-book, which is intended to teach Russian mining men how to read technical articles in the English language with the aid of a dictionary. The lessons are in part built around excerpts from British journals such as "The Colliery Guardian," in part around non-technical texts of a propagandist character. Perhaps the most interesting aspect of this book is that it should have been written at all.

Izbrannye trudy. (Selected works) of V. G. KHLOPIN. Vol. ii. Pp. 306. Academy of Sciences, Moscow, 1957. 18r. 85k.

This volume includes reprints of 18 papers by Khlopin on geochemistry principally on the rare gasses and the radioactive elements.

Kurs mineralogii. (Course in mineralogy.) By A. G. BETEKHTIN. Pp. 558, Figs. 389. Gosgeoltekhizdat, Moscow. 2nd edition, 1956. 19r. 70k.

This is approximately the Russian equivalent of Dana's "Textbook of Mineralogy." Since it was first published in 1951 it has been translated into German, Chinese, Roumanian, Czech and Polish. The present printing is 25,000 copies. An introductory chapter on the history of mineralogy concerns itself almost wholly with Russian contributions. The main work, made up of systematic descriptions of minerals in technical vocabulary, can be put to unscheduled uses in arousing the interest of western students in the Russian language.

Izverzhennye gornye porody. (Eruptive rocks.) By A. N. ZAVARITSKII. Pp. 479, figs. 215. Academy of Sciences, Moscow, 1956. 31r.

A standard text-book on the petrography of the igneous rocks, directed towards senior University classes. More than two-thirds of the 500-odd references quoted are in western languages. The figures are principally photomicrographs, mostly after Harker and Reinisch though they lack the delicacy of the originals. Introductory chapters review the different systems of classification of rocks and theories of petrogenesis.

Tufolavy. (Tufolavas.) Pp. 68, figs. 38. Academy of Sciences (Trans. Inst. Volcanology, No. 14), Moscow, 1957. 3r. 65k.

Current interest in tufolavas or ignimbrites has prompted this collection of five well-written papers on general questions of the formation of these rocks, and on particular problems of the ignimbrites in the northern Tyan Shan.

Voprosy geologii i mineralogii Kol'skogo Poluostrova. (Contributions to the geology and mineralogy of the Kola Peninsula.) No. 1. Pp. 191. Academy of Sciences, Moscow, 1958. 11r. 95k.

This well-produced volume from the Kola filial of the Academy of Sciences comprises nine papers mainly of economic interest—on the Sudbury-like norites of Moncha tundra, on the Yukspor apatite-nepheline complexes, on yttrium-bearing pegmatites, on lovchorrite veins, and on the copper-nickel ores of Ortoaivi (formerly in Finland). There are many new chemical analyses. Further volumes of this new periodical are announced for 1958.

Metody izucheniya osadochnykh porod. (Methods of study of the sedimentary rocks.) Edited by N. M. STRAKHOV AND OTHERS. In two volumes. Vol. i (parts 1–2), pp. 611 (incl. 74 pl.), 33r. 60k.; vol. ii (parts 3–6), pp. 564 (incl. 15 pl.), 32r. 10k. Gosgeoltekhizdat, Moscow, 1957.

This outstanding new text, to which some 40 authors have contributed, is compiled in six parts which are published in two large volumes. Part 1 deals with the observation of sedimentary rocks in the field, making special reference to structures, textures and facial analysis, whilst part 2 is concerned with all aspects of the mineralogical-petrographical study of sediments in the laboratory. Part 3 gives extensive coverage to the chemical study of sediments; part 4 is taken up principally with the economic geology of the sedimentary rocks; part 5 embraces geochemical, mineralogical, palaeontological and structural-textural criteria for facial analysis; and finally part 6 discusses the use of similar criteria in stratigraphical correlation. The work seems to be one of the more ambitious teaching projects of recent years, and undoubtedly it will greatly stimulate the study of sedimentary petrology in Russia. The many plates are clear and instructive, a few of them being printed in colour. A French translation is in preparation at the Bureau de Recherches Géologiques et Minières in Paris.

Osnovy litologii i geokhimii kory vyvetrivaniya. (Principles of lithology and geochemistry of the crust of weathering.) By K. I. LUKASHEV. Belorussian Academy of Sciences, Minsk. 1958.

A text-book on the processes and products of rock weathering, based principally upon Soviet literature. As with most Russian text-books, the work lacks an index. A bibliography extends to 18 pages.

Sovetskaya Geologiya. (Soviet Geology.) No. 60. Pp. 211. Gosgeoltekhizdat, Moscow. 1957. 8r. 80k.

A special number of this periodical publication is given over to papers detailing progress in geological studies since the Revolution, and comprises useful reviews of the advances in geological mapping, stratigraphy, mineralogy, theories of ore genesis, geological and geophysical prospecting, research on mineral fuels, and other topics.

C. F. DAVIDSON

UNIVERSITY OF ST. ANDREWS,
SCOTLAND,
Aug. 6, 1958

Elements of Geology. By JAMES H. ZUMBERGE. Pp. 382; figs. 198. Johr Wiley and Sons, New York, 1958. Price, $5.50.

This striking book is prepared for a one-semester course, including both physical and historical geology. Eleven chapters deal with physical geology and 6 with historical geology although both parts are about equal in pages. It was planned for students in other sciences and engineering rather than for those who plan to major in geology. It is clearly written and heavy terminology is reduced to a minimum. The numerous illustrations are fresh and good. A striking feature is that each chapter is opened by an excellent two-page photograph depicting the subject of the chapter.

After an introduction the second chapter gives an account of the place of the earth in the universe. This is followed by the "Earth's Crust" that deals with rocks and minerals and their origin. Under "Geologic Forces" the author takes up internal and external forces that modify the earth. The following 7 chapters consider earthquakes, weathering, wind action, ground water, rivers, glaciation and work of the sea. The next 6 chapters are historical geology from Precambrian to the Pleistocene. Throughout the author stresses uniformitarianism. The material is taken up in a manner and style that commands the interest of the reader.

The book will certainly serve the purpose for which it was written and will make interesting reading for the layman as well.

The Petroleum Chemicals Industry, 2nd Ed. By RICHARD F. GOLDSTEIN. Pp. 458; figs. 36; charts and tables. John Wiley & Sons, New York, 1958. Price, $16.50.

This volume is a part of the "General and Industrial Chemistry Series," under the editorship of H. M. Bunbury. Petrochemicals have become an important part of the modern industrial chemistry and are an important source of supply of bulk raw materials for the chemical industry as a whole. This second edition adds new chapters on the history of petroleum chemicals and on the industry itself. Most of the former chapters have been largely or completely rewritten so as to bring this edition up to date with the growth that has taken place. Its 22 chapters delve extensively into the organic chemistry of the numerous constituents of petroleum and of the part they play in industry, and the economics involved. Four appendices carry tabular matter relating to hydrocarbons, and statistics of production and consumption of petroleum, and of synthetic organic chemicals unrelated to coal tar.

The volume should prove to be a handy reference to all interested in petrochemicals.

Getting Acquainted with Minerals, 2nd Ed. By G. L. ENGLISH and D. E. JENSEN. Pp. 362; figs. 355. McGraw-Hill Book Co., New York, 1958. Price, $6.95.

Here is the amateur mineral collector's delight. The author tells one how to start a mineral collection, the equipment needed, means of identification, and sources of minerals. He also tells how to clean, classify and display minerals. This new edition brings the amateur up-to-date on fluorescent and radioactive minerals and on crystals. His arrangement is alphabetical so that one can find the information needed quickly and easily. But in addition there are 36 pages of tables for running down minerals based on hardness, color, and streak. The book

also includes a chapter on rocks and their identification, a section on economic minerals, and one on crystallography. Many illustrations assist in the techniques and the identification of minerals.

This book is highly recommended for the amateur mineralogist.

Steinsalz und Kalisalze, Part I. By FRANZ LOTZE. Pp. 466; figs. 266. Gebruder Borntraeger, Berlin, 1957. Price, DM 58.80.

The author of this good-sized volume is Professor of Geology and Paleontology at the University of Münster. His preceding book was entitled "Steinsalz und Kalisalz, Geologie" and appeared in 1938. This volume brings the subject matter up-to-date, and has been considerably enlarged.

The opening chapters take up the general occurrence and mineralogy of the salt minerals. These are followed, under the heading of the origin of salt deposits, by discussions of the origin, chemistry, and occurrence of present-day salts in surficial waters such as streams, springs, ground water, desert accumulations, inland seas, and of the oceans. Following this are chapters on salt deposits of different geologic ages and their origin. Other chapters deal with the metamorphism and tectonics of salt deposits and of the relationship between salt and petroleum.

A valuable part of the volume is a very complete bibliography of 65 pages, divided into sections corresponding with the chief divisions of the subject matter of the book.

BOOKS RECEIVED

JAMES M. ALLEN AND JOHN W. SALISBURY

The Structure of Steel. EDWIN GREGORY and ERIC N. SIMONS. Pp. 176; figs. 72. Philosophical Library, New York, 1958. Price, $10.00. *A nontechnical explanation of the metallurgical structure of steels and steel alloys, for students, engineers, and buyers of steel; too high priced.*

The Exploration of Time. R. N. G. BOWEN. Pp. 142; figs. 40. Philosophical Library, New York, 1958. Price, $6.00. *A discussion of the various methods of computing time; astrophysical, botanical, zoological, geological, geographical, archaeological, anthropological, meteorological, paleontological, and geochronometric.*

Endogennoe rudoobrazovanie i endogennye rudnye mestorozhdeniya: bibliograficheskii ukazatel' za 1945–1954 gg. (Endogenetic ore-formation and endogenetic ore deposits: a bibliography for 1945–1954.) Pp. 82. Price, 4 r. Moscow (Academy of Sciences), 1958. *More than 1,800 works published in the U.S.S.R. within the decade are listed with full bibliography in a very broad system of classification. Unfortunately there is no subject index.*

Minerals Yearbook 1954. Volume II. Fuels. Pp. 465; figs. 15; tbls. Price, $2.25. U. S. Govt. Printing Office, Washington, D. C., 1958. *Statistics of production and utilization for coal, coke, petroleum, natural gas, asphalt, and their by-products.*

Research on Power from Fusion and Other Major Activities in the Atomic Energy Programs, January–June, 1958. Pp. 410. Price, $1.25. U. S. Atomic Energy Commission, Washington, 1958. *A summary of the work being done in the many fields of nuclear research.*

The Cretaceous Fossils of New Jersey. Pt. I, Porifera, Coelenterata, Annelida, Echinoidea, Brachiopoda and Pelecypoda. H. G. RICHARDS AND OTHERS.

Pp. 266; pls. 46. Dept. of Conservation and Economic Development, Trenton, 1958. *A revision of Weller's earlier work which includes description, range, type, and occurrence of each type.*

Review. Vol. I, No. 18, A Survey of the Factors Controlling Metallic Diffusion from the Gas Phase. R. L. SAMUEL. Pp. 42; figs. 23. Murex Limited, Rainham, Essex, England, 1958. *A largely theoretical discussion of the processes of diffusion coating metals.*

Exposicion de Cartas Geologicas. Resultado y Estudio Critico e Historico Sobre Cartografia Geologica. T. G. CASTELLANOS. Pp. 49; pls. 3. Academia Nacional de Ciencias, Miscelánea No. 35, Córdoba, Argentina, 1958. *In Spanish.*

Tenth Annual Report of the Joint Coal Board for the Financial Year 1956–1957. S. F. COCHRAN, Chairman. Pp. 69; figs. 18; misc. tables. Sydney, Australia, 1957. *Statistics of coal production and use in Australia during the year 1956.*

Contribution a la Carte Geologique de la Region Comprise Entre la Rive Gauche du Fleuve Congo et Lufu (Bas-Congo). B. SEKIRSKY. Bull. 8, Fasc. 1. Service Géologique du Congo Belge et du Ruanda-Urundi, 1958. Pp. 12; figs. 5; geological map. *Brief notes on structure and stratigraphy of an area in the lower Congo. In French.*

Rapports Annuels pour L'Année 1957. Pp. 33. Musée Royal du Congo Belge, Tervuren, 1958. *Report of work done in general geology, paleontology and mineralogy during 1957. In French.*

Age Determination of Some Granitic Rocks in California by the Potassium-Argon Method. G. H. CURTIS, J. F. EVERNDEN, and J. LIPSON. Pp. 16; figs. 4; tbl. 1. California Div. Mines Spec. Rept. 54, San Francisco, 1958. Price, 50 cents. *Dating of Nevadan intrusions suggests that the Holmes time scales are incorrect and that the length of the Jurassic is at least 40 million years. Work with Coast Range intrusions indicates a strike-slip displacement along the San Adreas fault of at least 300 miles.*

Administration Report of the Government Mineralogist for 1957. Pt. IV—Education, Science and Art. L. J. D. FERNANDO. Pp. 19. Price, 50 cents. Printed on the Orders of Government at Government Press, Ceylon, Colombo, July, 1958.

La Chronique des Mines D'Outre-Mer et de la Recherche Minière. Pp. 25. Price, 350 fr. Bureau d'Études Géologiques et Minières, Paris, June, 1958. *A discussion of the analytical methods used in the various fields of igneous and economic geology. With annotated bibliography. In French.*

Notice Explicative sur la Feuille Mayoumba-Ouest. J.-P. DÉVIGNE and D. REYRE. Pp. 43. Geologic map, scale 1:500,000. Gouvernement Général de L'Afrique Equatoriale Française, Paris, 1957. *Brief notes on geography, sedimentary and igneous geology, structure, and economic geology for an area on the Atlantic coast of Gabon in French Equatorial Africa.*

Pillow Lavas from Mysore State, India. C. S. PICHAMUTHU. Pp. 26; pls. 12; fig. 1; tbl. 1. Mysore Geologists' Association Bull. 15, Bangalore, 1957. *The distribution, mode of occurrence, physical characteristics, petrography, and chemical composition of some of these pillow lavas. Interesting metamorphic effects due to granitic intrusions.*

The Mineral Wealth of Madhya Pradesh. Vol. I, No. 4, Raipur Dept. of Geology and Mining, Raipur, 1958. *Contains the Rihand Valley, the Bauxite Deposits of Madhya Pradesh, etc.*

The Potosi Tungsten District Madison County, Montana. T. H. EYDE. Pp. 51; pls. 4; tbls. 2. Montana Bureau of Mines and Geology, Information Circ. 21, Butte, 1958. *Narrow veins with erratic metal content present difficult mining problem. Suggests thorough prospecting by drifting along veins, and consolidation of all properties into one operating unit if sufficient ore reserves are found.*

Scientific Activities in Six State Governments. Summary Report on a Survey, Fiscal Year 1954. Pp. 62; figs. 7; tbls. 20. National Science Foundation–58–24, Washington, 1958. Price, 40 cents. *Research and development accounted for the major share of expenditures for scientific activities in these representative states.*

Boletín de la Universidad Nacional de Ingeniería, Serie IV, Tomo XXXI. Pp. 86. Universidad Nacional de Ingeniería, Lima, Peru, 1958. *Treatment and utilization of coal; various short notes. In Spanish.*

Catalogue of the Mineral Localities of South Carolina. EARLE SLOAN. Pp. 505; pls. 11; figs. 18; tbls. 9. Reprinted by South Carolina State Development Board, Division of Geology, Columbia, 1958. Price, $2.75. *Concise descriptions of mines and prospects with map showing their locations as well as a small amount of the geology of South Carolina as known in 1908.*

Virginia Manganese Minerals and Ores. A Selected Bibliography with Excerpts. A. A. PEGAU. Pp. 24. Virginia Div. of Mineral Resources Circ. 7. Charlottesville, 1958.

Stratigraphy of the Lower Murchison River Area and Yaringa North Station, Western Australia. D. JOHNSTONE, M. A. CONDON, and P. E. PLAYFORD. Pp. 4; fig. 1; tbl. 1. Journal of the Royal Society of Western Australia, Vol. 41, pt. 1, Perth, 1958. *Cretaceous stratigraphy of the west coast of Australia.*

Bureau of Mineral Resources, Geology and Geophysics—Australia, 1957–1958.

The Australian Mineral Industry—Quarterly Review and Quarterly Statistics. Vol. 10, No. 4. Pp. 39; tbls. 11. Price, 3 sh. *Statistics of mineral production and use.*

Bull. 49. The Cambrian Geology of Australia. A. A. ÖPIK AND OTHERS. Pp. 284; figs. 31. *Petrology, structure, distribution, etc., of the Cambrian rocks in Australia.*

Geological Society of America—New York City, 1957–1958.

Memoir 72. Coastal Sand Dunes of Oregon and Washington. W. S. COOPER. Pp. 169; pls. 22; figs. 12; tbls. 8. *Detailed description of environment, forms, and processes. Authoritative.*

Teaching Aids and Allied Materials in Engineering Geology. G. A. KIERSCH. Pp. 35. Price, 75 cents. *A brief resumé of the status of engineering geology in American schools. Appendices gives lists of colleges, teaching aids available, suggested courses, employment opportunities.*

Illinois Geological Survey—Urbana, 1958.

Bull. 83. Petroleum Industry in Illinois in 1956. Pt. I. Oil and Gas Developments; Pt. II. Waterflood Operations. A. H. BELL, VIRGINIA KLINE, and D. A. PIERRE. Pp. 173; figs. 29; tbls. 16. *Details of development and production are discussed by counties. Reserves estimated at 701.6 million barrels.*

Bull. 84. Petrographic and Coking Characteristics of Coal. Laboratory Study of Illinois Coal Seams Nos. 5 and 6. C. E. MARSHALL, J. A. HARRISON,

J. A. SIMON and M. A. PARKER. Pp. 120; pls. 9; figs. 90; tbls. 36. *Factors investigated which influence coking character were: petrographic composition, charging temperature, final coking temperature, final coking period, particle size and size distribution, and influence of "asphaltene" when blended with coal.*

Rept. of Investigations 207. Oxidation of Coal. G. R. YOHE. Pp. 51. *A summary and review of the literature on coal oxidation with a 315 reference bibliography appended.*

Rept. of Investigations 208. Water Sorption Properties of Homoionic Clay Minerals. W. A. WHITE. Pp. 46; figs. 16; tbls. 4. *Characteristics of the water sorption curves tend to reflect the structure and properties of the clay minerals.*

Circ. 256. Geology and Petrology of the Anvil Rock Sandstone of Southern Illinois. M. E. HOPKINS. Pp. 49; pls. 2; figs. 14; tbls. 5. *This sandstone fills channels that have been eroded above, and in places through, No. 6 Coal, the principal minable coal in Illinois. Distribution and occurrence of these channels may be important in exploration and exploitation of No. 6 Coal in Illinois.*

India Geological Survey—Delhi, 1956–1957.

Bull. 13. Clay-Shale Deposits Suitable for Use in the Manufacture of Cement at Sindri, Manbhum, Bihar. D. R. S. MEHTA. Pp. 22; pl. 1; tbls. 3. Price, 1 sh. 6 d. *Description of clay and shale deposits and discussion of utilization in the manufacture of Portland cement.*

Memoir 84. Pt. I. A Revision of the Geology and Coal Resources of the Raniganj Coalfield. D. R. S. MEHTA. Pp. 113; pls. 5; tbls. 15. Price, 12 sh. 6 d. *A revision of the stratigraphy and revaluation of reserves.*

Geological Survey of Japan—Hisamoto-chō, Kawasaki-shi, 1958.

Explanatory Text of the Geological Map of Japan. Horokanai (Asahikawa-39). S. IGI, K. TANAKA, M. HATA, and H. SATŌ. Pp. 64; pls. 3; figs. 7; tbls. 2. *Areal geology of igneous and metamorphic terrain in west-central Hokkaidō. Map, scale 1:50,000. English summary.*

Bulletin of the Geological Survey of Japan, Vol. 9, No. 5. Pp. 90; figs. 50. *Several papers dealing with stratigraphy, ore deposits, ground water and hot springs. In Japanese; English abstracts.*

Bulletin of the Geological Survey of Japan, Vol. 9, No. 6. Pp. 79; pls. 2; figs. 40; tbls. 20. *Five articles dealing with such diverse subjects as resistivity measurement in drill holes, geology as applied to dam site selection, ground water, hot springs, and the properties of a coal in the Gumma Prefecture. In Japanese; English abstracts.*

Rept. 178. Studies on the Brackish Water. I. Geochemical Studies of Lake Hamana-ko—On the Genesis of Natural Gas Accumulation. K. MOTOJIMA and S. MAKI. Pp. 28; pls. 4; figs. 14; tbls. 17. *In Japanese; English summary.*

Rept. 179. Studies on the Brackish Water. II. Determination of the Chemical Constituents of Interstitial Water in Lake Mud and the Experiment on the Dissolution of Organic and Inorganic Substances from Mud of Lake Hamana-ko. S. OANA. Pp. 15; figs. 14; tbls. 5. *In Japanese; English summary.*

Rept. 180. Studies on the Brackish Water. III. Recent Foraminifera from the Brackish Lake Hamana-ko. Y. ISHIWADA. Pp. 21; pls. 2; figs. 20; tbls. 2. *In Japanese; English summary.*

Kansas Geological Survey—Lawrence, 1958.

Bull. 130, Pt. 1. Quaternary Geology and Ground-Water Resources of Kansas River Valley Between Bonner Springs and Lawrence, Kansas. A. E. DUFFORD. Pp. 96; pls. 8; figs. 10; tbls. 6. *Adequate ground-water is available for future industrial and irrigational expansion.*

Vol. 14. Geology, Mineral Resources and Gound-Water Resources of Elk County, Kansas. Pp. 55; pls. 4; figs. 11; tbls. 11. *Geology of and resources of an area in southeast Kansas. Oil, gas and limestone are the important economic products.*

The Petroleum Industry in Kansas. E. D. GOEBEL. 1 Plate. *Map (1" = 10 miles) showing oil and gas pools, pipe lines, oil refineries, natural gasoline, carbon black and helium plants.*

Quebec Department of Mines—1958.

Geological Rept. 79. Bignell Area. J. E. GILBERT. Pp. 38; pls. 6; tbl. 1; map 1:63,360. *Areal geology, structure and stratigraphy of a region south of Lake Mistassini.*

Geological Rept. 80. Radioactive Mineral Occurrences of the Province of Quebec. D. M. SHAW. Pp. 49; figs. 11; tbls. 2. *Mineralogy and geochemistry of uranium, prospecting methods, geologic setting of deposits, and description of properties.*

Southern Rhodesia Geological Survey—Salisbury, 1957.

Bull. 44. Pt. I. The Geology of the Eastern Portion of the Hartley Gold Belt. J. W. WILES. Pp. 103; pls. 7; figs. 6; tbls. 3. *Interesting geological description of the Great Dyke.*

Bull. 44. Pt. II. Gold Deposits and Mines. J. W. WILES. Pp. 180; pls. 10; figs. 7. *Descriptions of individual mines.*

U. S. Geological Survey—Washington, D. C., 1957–1958.

Bull. 1052-D. Magnetic-Doublet Theory in the Analysis of Total-Intensity Anomalies. R. G. HENDERSON and I. ZIETZ. Pp. 159–186; figs. 17; tbls. 4. Price, 15 cents. *Discusses typical magnetic-doublet profiles and their use in the interpretation of aeromagnetic maps.*

Bull. 1059-D. Selected Annotated Bibliography of the Geology of Uraniferous and Radioactive Native Bituminous Substances, Exclusive of Coals in the United States. H. N. JONES. Pp. 177–203; pl. 1. Price, 45 cents. *Indexed according to author, geographic area, stratigraphic unit, and subject.*

Water-Supply Paper 1306. Compilation of Records of Surface Waters of the United States through September 1950. Pt. 3-B. Cumberland and Tennessee River Basins. Prepared under direction of J. V. B. WELLS. Pp. 353; pl. 1; figs. 2; tbls. 978. *Monthly and yearly summaries of streamflow and reservoir data collected by 326 gaging stations.*

Water-Supply Paper 1378. Geology and Ground-Water Resources of the Lower South Platte River Valley Between Hardin Colorado, and Paxton Nebraska. L. J. BJORKLUND, R. F. BROWN and H. A. SWENSON. Pp. 431; pls. 4; figs. 17; tbls. 7. *In the areas where irrigation supplies are obtained wholly from wells, the water levels declined steadily during the period 1940–50.*

Water-Supply Paper 1427. Geology and Ground Water in the Santa Rosa and Petaluma Valley Areas Sonoma County, California. G. T. CARDWELL. Pp. 273; pls. 8; figs. 10; tbls. 27. *Deposits of late Tertiary and Quaternary age are the most important aquifers. Local overdevelopment is indicated in the vicinity of Petaluma, but elsewhere there is no overdraft, and ground-water resources have large potential.*

Water-Supply Paper 1440. Surface Water Supply of the United States 1956. Pt. 6-B. Missouri River Basin below Sioux City, Iowa. Prepared upder direction of J. V. B. WELLS. Pp. 487; figs. 3; tbls. 493. *Runoff in the area covered by this report during 1956 was generally below median to deficient. Drought conditions existed in Iowa and Missouri.*

SCIENTIFIC NOTES AND NEWS

RALPH TUCK has recently retired as chief geologist of the United States Smelting, Refining and Mining Co. and is engaged in consulting work in mining geology at Salt Lake City, Utah.

SAMUEL H. DOLBEAR and PARKE A. HODGES of Behre Dolbear and Co. are in Europe on a professional mission which has taken them to England, France, Germany, Denmark and Sweden.

A new technique has been developed by Battelle Memorial Institute to be used extensively in the development of alloys for nuclear reactors and gas turbines as well as for many other purposes. The Chromalloy Corp. and Chilean Nitrate Sales Corp. will produce ultra pure chromium metal through the use of an iodide chromium process.

The American Association of Petroleum Geologists will hold its 44th annual meeting at Dallas, Texas, March 16–19, 1959. The Society of Economic Paleontologists and Mineralogists will also hold its 33rd annual meeting at the same time and place. The convention theme will be a review of the Fundamentals of Oil Finding—Application of Geology, Geophysics, and Economics.

WILLIS M. JOHNS has been assigned as geologist-in-charge of the field station established in Kalispell by the Montana Bureau of Mines and Geology.

RUDOLPH C. GEBHARDT, geologist and mining engineer, has been named manager of E. J. Longyear Co.'s mining division, succeeding Dr. DONALD M. DAVIDSON who became president of the company on July 1. ROBERT D. LONGYEAR of Minneapolis, former president, has assumed the newly created position of chairman of the board.

HENRY SEAWELL BROWN has been named assistant professor of geological engineering at North Carolina State College. Formerly he headed the geology and geography department at Berea College, Kentucky.

SHELDON C. BERGMAN has transferred from the Mineral Deposits Branch to the Foreign Geology Branch of the U. S. Geological Survey where he will work on nonmetallic mineral resources with the Philippine Bureau of Mines under an ICA program.

VICTOR DOLMAGE, a director of Cariboo Gold Quartz Mining Co., has been elected to the newly created office of vice president.

ROBERT D. FERGUSON has retired after 35 years with the U. S. Geological Survey.

CHARLES C. GODDARD, JR. replaces EDWARD P. SHEA as geologist of the Anaconda Co.'s Butte Mines. Shea has been promoted to company geologist for Montana and is succeeded as mines geologist by WALLACE A. O'BRIEN.

JOHN F. IVANAC, senior geologist for Cerro de Pasco Corp. in Morococha, Peru, has been transferred to Cerro de Pasco where he is in charge of the geology and assay departments.

J. E. EVERTS, formerly development geologist for Phillips Petroleum Co. in the Strategic Minerals section, is now mining engineer in the Mining and Milling department.

EUGENE LINDSEY, formerly with Anaconda Co., is now associated with Wisser & Co., consulting geologists, San Francisco.

DONALD CHAPIN BOARDMAN, professor of geology at Wheaton College, has been named chairman of the college's newly created department of geology.

ROBERT B. HOY, formerly chief geologist of northeastern United States for New Jersey Zinc Co., is now assistant to the chairman of the earth sciences department of Standford Research Institute, Menlo Park, Calif.

JOHN S. RINEHART, assistant director of Smithsonian Astrophysical Observatory and astronomy-research associate at Harvard University, became a full professor of mining engineering at the Colorado School of Mines this fall.

JACK H. MCWILLIAMS, geological engineer for Aluminum Co. of America since 1942, has been made manager of ore exploration for the company's mining division.

DR. ALEXANDER NEWTON WINCHELL, prominent mineralogist and petrologist, died on June 7 in New Haven, Conn., at the age of 84.

FRANK FITCH GROUT, Professor Emeritus of Geology at the University of Minnesota and former Director of the Minnesota Geological Survey, died on August 1.

CHARLES ELIJAH DECKER died on August 23 at the age of 89.

JOHN BERNARD REESIDE, JR. died at the age of 69. He began working for the U. S. Geological Survey in 1912 and continued in that service throughout his life. He was chief of the Section of Paleontology and Stratigraphy from 1932 to 1949. He became president of the Paleontological Society in 1943.

A. NOVITZKY is presently in Venezuela as representative of the "Instituto Venezolano del Hierro y del Acero" at the Naricual coal mine, which will furnish coal for the new steel industry of that country. His address there is: A. Novitzky, Instituto Venezolano del Hierro y del Acero, Edif. Mil, Este 2, 201, Los Caobos, Caracas, Venezuela. During the past ten years, he was professor at the Universities of Cuyo, Argentina and La Paz, Bolivia.

JAMES J. SCARDINO left his position as mine geologist with Wah Chang Mining Corp. to become geologist for the State of Idaho Dept. of Highways.

HERBERT E. HAWKES, JR. is now professor of mineral exploration at the University of California.

BAHNGRELL W. BROWN, who was acting head of the Montana School of Mines Dept. of Geology, now is an associate professor at Mississippi Southern, Hattiesburg, Miss.

EUGENE H. LINDSEY, formerly with the Anaconda Company, has joined the consulting geological staff of Wisser and Cox in San Francisco.

DR. TROY L. PEWE has been appointed head of the geology department of the University of Alaska's School of Mines.

EMMONS MEMORIAL FELLOWSHIP

The S. F. Emmons Memorial Fellowship in Economic Geology is available for the academic year 1959–60, with a stipend of $1,600.00. Applications and accompanying testimonials should be submitted not later than February 15, 1959.

Applicants should be qualified by training and experience to investigate some problems in Economic Geology and should submit a definite statement of the problems to the Committee, under whose supervision the work may be undertaken at any institute approved by them. The Fellow must give entire time to the problem, which may be used for a doctoral dissertation. Application blanks may be obtained from Alan M. Bateman, Yale University, H. E. McKinstry, Harvard University, Charles H. Behre, Columbia University, or the Secretary, Columbia University.

INDEX TO VOLUME LIII

[NOTE.—In this index the title to principal papers and headings of departments, as *Discussions*, are in italics.]

Abbott, A. T., *Occurrence of gibbsite on the island of Kauai, Hawaiian Islands*, 842–853

Abdullaev, Kh. M., on tin, 903
review of book by, 1050

Abitibi West County, Quebec, Canada, Porphyritization in Destor and Duparquet Townships (Graham), 737

Abstracts—
Action of crude oils on uranyl solutions (Gruner) 919
Alkali feldspars from ore and non-ore bearing parts of some intrusive porphyries (Kuellmer, Carmen, and Renault), 931
Alteration in part of the United States mine, West Mountain (Bingham) district, Utah (Stephens and Sand), 932
Alteration of biotite under mesothermal conditions (Schwartz), 164
Banded pyrite deposits of Minas Carlota, Cuba (Hill), 967
Beryllium detector for field exploration (Brownell), 916
Chamositic iron ore deposits near Tajmište, Western Macedonia Yugoslavia (Page), 1
Chemical analyses of the fluid inclusions in a group of New Mexico minerals (Ames), 473
Chemical character of water in the igneous and metamorphic rocks of North Carolina (LeGrand), 178
Chemical composition as a guide to the size of sandstone-type uranium deposits in the Morrison formation of the Colorado Plateau (Miesch *et al.*), 923
Chemical environment of pitchblende (Miller), 521
Coal geology and the coal industry (Cady), 511
Cold acid extraction of copper from soils and sediments—A proposed field method (Canney and Hawkins), 877
Columbium-rare earth titanium mineralization at St. Joseph du Lac, Oka area, Two Mountains County, Quebec (Sclar and Smerchanski), 926
Comparison of the physical properties of uranium-bearing rocks in the Colorado Plateau and the Gulf Coast of Texas (Manger), 922

Abstracts—Continued
Contribution on the Hector, California, bentonite deposit (Ames, Sand, and Goldich), 22
Design of simple punched card systems with reference to geochemical problems (Breger), 325
Deuteric alteration of some aplite-pegmatites of the Boulder batholith, Montana, and its possible significance to ore deposition (Neuerburg), 287
Distribution of copper, zinc and minor metals in the southeast Missouri lead district (Davis), 917
En echelon folding (Campbell), 448
Environmental control of sedimentary iron minerals (Huber), 124
Evaluation of uranium ore guides, Monument Valley, Arizona and Utah (Evensen and Gray), 639
Evidence on the origin of Blind River uranium—A progress report (Derry), 918
Factors controlling the localization of ore deposits in the Shullsburg area, Wisconsin-Illinois zinc-lead district (Reynolds), 141
Galena in pyrometasomatic deposits (Geijer), 210
Genetic aspects of the monazite and columbium-bearing rutile deposits in northern Lemhi County, Idaho (Anderson, 913
Geochemical exploration at Darwin mines, California (Austin and Nackowski), 913
Geochemistry of coal (Breger), 823
Geologic causes for failure of Lone Pine Reservoir, east central Arizona (Kiersch), 854
Geologic characteristics of fluorspar deposits in the western United States (Peters), 663
Geology and ground-water conditions in the Neyveli lignite area, south Arcot district, Madras State, India (Jones and Subramanyam), 920
Geology and metamorphism of the Nairne pyritic formation, a sedimentary sulfide deposit in South Australia (Skinner), 546
Geology of the Mt. Lyell mines, Tasmania (Wade and Solomon), 367

Abstracts—Continued
Gold-copper deposits near Santa Maria del Oro, Durango, Mexico (Davis), 918
Ground water conditions and the relation to uranium deposits in the Gas Hills area, Fremont and Natrona Counties, Wyoming (Marks), 923
Influence of ionic substitution on the stability of micas and chlorites (Devries and Roy), 958
Iron-titanium oxide minerals, rocks, and aero-magnetic anomalies of the Adirondack area, New York (Balsley and Buddington), 777
Isotopic relations in uranium deposits of the Colorado Plateau (Miller and Kulp), 924
Isotopic study of some Colorado Plateau ores (Miller and Kulp), 937
Lead-arsenic-sulfide ore deposit of Bacu Locci (Sardinia—Italy) (Zucchetti), 867
Limestone aquifers of Maryland (Otton and Richardson), 722
Liquid of inclusions in sulfides from Tri-State (Mo.-Kans.-Okla.) is probably connate in origin (White), 929
Manganese ores from the Kuruman district, Cape Province, South Africa (Frankel), 577
Manganese ores of the Nsuta deposit, Ghana (Sorem and Cameron), 927
Measurement of the solubility of ZnS in H_2S-saturated H_2O (Barnes), 914
Mineralogy and geochemistry of the uranium deposits of the Grants district, New Mexico (Weeks and Truesdell), 932
Minerals of the cassiterite-bearing veins at Irish Creek, Virginia, and their paragenetic relations (Glass, Koschmann, and Vhay), 65
Nickel-gold ore of the Mackinaw mine, Snohomish County, Washington (Milton and Milton), 426
Niobium-titanium-rare earth minerals of Ravalli County, Montana, and Lemhi County, Idaho (Heinrich *et al.*), 930
Occurrence of gibbsite on the island of Kauai, Hawaiian Islands (Abbott), 842
Ore controls in the Karnes County uranium area, Texas (MacKallor and Bunker), 922
Origin of certain chromite deposits of the eastern part of the Bushveld Complex (Cameron and Emerson), 917
Origin of ore deposits of the Mississippi Valley type (Behre), 915
Origin of the Mississippi Valley type deposits (Amstutz), 930

Abstracts—Continued
Physical and chemical environment of Illinois-Kentucky fluorspar deposits (Nackowski), 925
Porphyritization in Destor and Duparquet Townships, Abitibi West County, Quebec, Canada (Graham), 737
Primary borates in playa deposits: Minerals of high hydration (Muessig) 925
Progress in leached outcrop studies (Kelly *et al.*), 921
Rank of coal and metamorphic grade of rocks of the Narragansett basin of Rhode Island (Quinn and Glass), 563
Redbed uranium occurrences in Pennsylvania (McCauley), 931
Reflectance of oxidized coals (Chandra), 102
Regional structure and lithology in relation to uranium deposits, Karnes County area, Texas (Eargle), 919
Relation of phosphorites to ground water in Beaufort County, North Carolina (Brown), 85
Relationship of ore to porphyry in the Basin and Range Province, U.S.A. (Stringham), 806
Scheelite in feldspathized granodiorite at the Victory mine, Gabbs, Nevada (Humphrey and Wyatt), 38
Sedimentary features of the ore deposits, Jefferson City mine, Tennessee (Kendall), 921
Some clues to the genesis of uranium deposits in the Laguna district, New Mexico (Moench), 924
Some sedimentary characteristics of uranium host rocks (Happ), 920
Structural sections and the third dimension (Knutson), 270
Suggestions on geochemical prospecting for manganese in northeast Tennessee (Bloss and Steiner), 916
Sulfur-isotopes and the origin of sandstone-type uranium deposits (Jensen), 598
Supergene copper-uranium deposits in northern Nova Scotia (Brummer), 309
Structural belts and mineral deposits of northwestern Argentina (Whiting), 929
Structural relations at the Hideout No. 1 uranium mine, Deer Flat area, San Juan County, Utah (Finnell and Gazdik), 949
Structure of the ore deposits at Santa Barbara, Chihuahua, Mexico (Scott), 1004
Technique for the extraction and partial chemical analysis of fluid-filled inclusions from minerals (Roedder), 235
Temperatures and depth of formation of sulfide ore deposits at Gilman, Colorado (Lovering), 689

Abstracts—Continued
Thermodynamic properties of some synthetic zinc and copper minerals (Barton and Bethke), 914
Time relations of intrusion, faulting, and mineralization at Leadville, Colorado (Tweto), 928
Titaniferous sedimentary rocks in the Cuyuna district, central Minnesota (Schmidt), 708
Tungsten mineralization in Hong Kong and the New Territories (Davis), 481
Uranium-bearing auriferous reefs at Jacobina, Brazil (Bateman), 417
Use of leachable uranium in geochemical prospecting on the Colorado Plateau. II. The distribution of leachable uranium in surface samples in the vicinity of ore bodies (Holland, Witter, Head, and Petti), 190
Use of water-well data in interpreting the occurrence of Upper Cretaceous aquifers in northeastern Lyon County, Minnesota (Rodis), 926
Zeolitic alteration of tuffaceous sediments and its relation to uranium deposits in the Karnes County area, Texas (Weeks, Levin, and Bowen), 928
Actinolite, 978
Adair, B. H., and Stringham, B., on Whitehorse monzonite, Nev., 807
Adams, J. A. S., and Pliler, R., discussion by, 621
Adams, J. A. S., and Weaver, C. W., on thorium: uranium ratios, 622
Adams, S. F., on quartz, 980
Adirondack area, New York, Iron-titanium oxide minerals, rocks, and aeromagnetic anomalies of the (Balsley and Buddington), 777
Aerial photos, landslides (review), 898
Africa, auriferous conglomerates, West and South Africa (discussion), 887
mineral resources (review), 628
South Africa, Shand memorial volume (review), 113
West Africa, conglomerates (discussion), 492
Agnew, A. F., *et al.*, on zinc deposits, 151
Agriculture, atomic energy applications (review), 223
Ahlfeld, F., review of book by, 765
Aikinite, 82
Akimoto, S., on ilmenite, 803
Alaska, geology (review), 769
Alberta, natural resources (review), 502
Albite, 555, 741
Aldrich, L. T., Wetherill, G. W., and Davis, G. L., on age determinations, Colo. Plateau, 944
Alexander, J. M., on Mt. Lyell district, Tasmania, 370
Alexandrov, E. A., on iron, 349
reviews by, 220, 899, 1050, 1055
Allan, J. C., on pyrite, 991
Allanite, 930
Allen, E. T., *et al.*, on pyrrhotite, 129
Allen, J. M., books received by, 630, 769, 905
Allen, J. M., and Salisbury, J. W., books received by, 115, 226, 358, 503
Allen, V. T., on resilication, 848
Allen, V. T., and Fahey, J. J., on pyroxenes, 1006
Allende, R., on Minas Carlota district, Cuba, 968
Almond, Hy, on copper, 879
Aloy, J., on uranium, 540
Alteration, dolomitization, Gilman district, Colo., 689, 692, 700
feldspar, 748, 751
fluorspar deposits, western U. S., 679
Gabbs scheelite district, Nev., 39
Lyell schists, Tasmania, 402
Moenkopi contact, Monument Valley, Ariz., 646
Shullsburg area, Wis., 161
tuff, California, 22
Utah, U. S. mine (abstract), 932
zeolite to hectorite, 36
zeolitic, Texas, Karnes Co. (abstract), 928
Alteration of biotite under mesothermal conditions (Schwartz), 164
Alteration of some aplite-pegmatites of the Boulder batholith, Montana, and its possible significance to ore deposition, Deuteric (Neuerburg), 287
Alteration zones, 288
Alunite, 173
Ames, L. L., Jr., *Chemical analyses of the fluid inclusions in a group of New Mexico minerals*, 473–480
gas absorption run by, 265
Ames, L. L., Jr., Sand L. B., and Goldich, S. S. *A contribution on the Hector, California, bentonite deposit*, 22–37
Amesite, 963, 964
Amsden, T. W., on Greenbrier-Pocono formational contact, 734
Amstutz, G. C., abstract by, 930
reviews by, 765
Analcite, 22
Anauxite, 171
Andalusite, 54, 554
Anderson, A. L., abstract by, 913
on fluorspar, Idaho, 670
Anderson, C. A., on biotite, 167
Anderson, G. E., on copper-nickel, 1045
Andradite, 211
Andrews, E. C., on ore deposits, 988
Angle of departure, 270, 272, 276
Angle of penetration, 270, 279
Angola, sedimentation, Rio Giraul (discussion), 491
Ankerite, 79

Annabergite, 429
Anomalous magnetization, 792
Anthracite, meta-anthracite, R. I., 563, 569, 573
Antonović, A., on iron, 4
Apatite, 73, 173, 216, 742
Apatite Series, 1046
Aplite, 43, 46, 741
Aplite-pegmatites of the Boulder batholith, Montana, and its possible significance to ore deposition, Deuteric alteration of some (Neuerburg), 287
Apparent plunge, 270, 279
Aquifers of Maryland, Limestone (Otton and Richardson), 772
Archeology, Stone Age (review), 115
Arctic, Soviet Arctic, geology (review), 766
Arfvedson, J. A., on UO_3, 522
Argall, G. O., on fluorspar, Colo., 670
Argentina, ore deposits and structural belts (abstract), 929
Arizona, Geologic causes for failure of Lone Pine Reservoir, east central (Kiersch), 854
biotite, alteration, 165
Colorado Plateau, lead-uranium ages, 941
copper, field determinations, 884
ore deposits and porphyries, 810
orthoclase, porphyry deposits (abstract), 931
uranium, sulfur isotope ratios, 603, 607
uranium near ore bodies, 190, 196, 200
Arizona and Utah, Evaluation of uranium ore guides, Monument Valley (Evensen and Gray), 639
Arizonite, 781
Arkansas, quartz, spectroscopy, 250
Arnold, R. G., on pyrrhotite, 556
Arsenic, occurrence in coal, 834
Arsenic-sulfide ore deposit of Bacu Locci (Sardinia—Italy), Lead (Zucchetti), 867
Arsenopyrite, 81, 834, 867, 872, 873, 1016
Ash, coal ash, geochemistry, 832
volcanic, titaniferous argillite, Minn., 708, 714
Ashley, G. H., on coal, Narragansett basin, R. I., 565
Atlases, Prentice-Hall world atlas (review), 768
Atomic age and our biological future (review), 627
Atomic energy, agriculture (review), 223
economics (review), 114
Aubrey, K. V., on germanium, 832
Auger, P. E., on pyrite, 982
Ault, W. V., on meteoritic sulfur, 608
Auriferous reefs at Jacobina, Brazil, Uranium-bearing (Bateman), 417
Austin, C. F., and Nackowski, M. P., abstract by, 913
Australia, Northern Territory, Rum Jungle uranium deposit (discussion), 892
Austria, anthracite, x-ray study, Leoben deposit, 571
Axelrod, J. M., *et al.*, on fluorescence, 300
Azároff, L. V., and Buerger, M. J., review of book by, 500

Babaev, K. L., and Isamukhamedov, I. M., on geology, Central Asia, 1054
Bacteria, alumina, liberation and migration, 850
hydrogen sulfide generation, 598, 613, 945
occurrence in brown coal, 826
sulfate reduction, 139
Bacu Locci (Sardinia—Italy), Lead-arsenic-sulfide ore deposit of (Zucchetti), 867
Bain, G. W., on quartz, 980
on vanadium, 659
Bain, H. F., on pitch-flat structures, 143
Baker, A. A., on folds, 954
on Monument Valley, Ariz.-Utah, 196, 640
Balk, R., on joints, 296, 956
Balsley, J. R., on aeromagnetic maps, Adirondacks, 779
Balsley, J. R., and Buddington, A. F., *Iron-titanium oxide minerals, rocks, and aero-magnetic anomalies of the Adirondack area, New York*, 777–805
on magnetization, 802
Balsley, J. R., Buddington, A. F., and Fahey, J., on magnetism, 802
Bancroft, M. F., on copper, 311
Banded pyrite deposits of Minas Carlota, Cuba (Hill), 966
Banding, ores, Bacu Locci sulfide deposit, Sardinia, 873
Bangham, D. H., on coal geochemistry, 824
Barghoorn, E. S., on cellulose, 825
Barite, 679, 685, 1017, 1039
inclusions in barite, 475
Barnes, H. L., abstract by, 914
Barrell, J., on contact metasomatism, 996
Barth, T. F. W., on fluorine, 665
Barth, T. F. W., and Rosenquist, T., on silicate melts, 345
Barton, P. B., Jr., and Bethke, P. M., abstract by, 914
Basak, N. G., *et al.*, on hydrogenation of coal, 830
Basalt, Cuyuna range, Minn., 708, 710, 716
Basin and Range province, U.S.A., Relationship of ore to porphyry in the (Stringham), 806
Bastin, E. S., on sulfate, 139
Bastin, E. S., and Hill, J. M., on pitchblende, 529
Batalov, A. B., on assimilation, 1054
Bateman, A. M., on metallogenic provinces, 988

Bateman—*Continued*
on quartz, 407
on secondary ore deposits, 875
review by, 224
Bateman, J. D., *Uranium-bearing auriferous reefs at Jacobina, Brazil*, 417–425
on conglomerates, 425
Beaufort County, North Carolina, The relation of phosphorites to ground water in (Brown), 85
Becraft, G. E., on alteration zones, 291
Bedding, 278
Beer's Law for uranyl ferrocyanide, 524, 525
Behre, C. H., Jr., abstract by, 915
on Leadville district, Colo., 821
on pitch-flat structures, 143
Behre, C. H., Jr., Scott, E. R., and Banfield, A. F., on ore bodies, 143
Belcher, R., on coal oxidation, 829
Belevtsev, Ya. N., review of book edited by, 894
Belgian Congo, uranium, Haut Katanga minerals (review), 767
Bell, H., III, *et al.*, on channels, 956
Bennett, R. R., and Meyer, R. R., on Coastal Plain sands, Md., 726
Benson, W. E., *et al.*, on Deer Flat area, Utah, 951
Bentonite deposit, A contribution on the Hector, California (Ames, Sand, and Goldich), 22
Berg, A., and Friedensburg, F., on arsenopyrite, 868
Berg, W. F., on concentration gradients, 253
Bergius, F., on cellulose, 824
Bergmann, G., *et al.*, on carbonyl groups, 829
Berl, E., on cellulose, 824
Berthold, S. M., analyses by, 710
Beryl, 75, 78
prospecting detector (abstract), 916
Beryllium, occurrence in coals, 835
Berz, K. C., on iron ores, 15
Betekhtin, A. G., on Cu-Fe-Ni-S system, 443
on skarn, 1053
review of book by, 1057
Betekhtin, A. G., *et al.*, review of book edited by, 899
Bibliography, anthracite, Narragansett basin, R. I., 575
Bacu Locci sulfide deposit, Sardinia, 876
biotite, alteration, 176
coal geochemistry, 836
copper, field determinations, 886
copper-uranium deposits, Nova Scotia, 323
fluorspar, western U. S., 687
gibbsite from basalt, Hawaii, 853
iron minerals, equilibrium and variables on stability, 139
Jacobina gold-uranium reefs, Brazil, 425
Bibliography—*Continued*
limestone aquifers, Maryland, 735
magnetization and magnetic anomalies, Adirondacks, N. Y., 804
mineralized porphyry intrusives, U. S., 810, 822
Mt. Lyell district, Tasmania, 415
Nairne pyritic formation, South Australia, 562
pitchblende, chemistry, 544
potash and saline minerals (review), 1060
pyrite, Minas Carlota district, Cuba, 999
quartz inclusions, analysis, 267
reflectance of coal, 108
sulfide ores, Gilman district, Colo., 706
Mackinaw mine, Wash., 447
sulfur isotopes and uranium deposits, 615
Tajmište iron ore district, Yugoslavia, 20
tin and tungsten (review), 765
uranium and thorium minerals, 307
uranium ore guides, Monument Valley area, Ariz.-Utah, 661
zinc-lead deposits, Shullsburg area, Wis., 163
Bichan, W. J., on replacement, 996
Big Indian Wash area, uranium in soils, Utah, 190
Billingsley, P., and Locke, A., on ore districts, 618
Biography, Palissy, B. (review), 113
Biological future and the atomic age (review), 627
Biotite, 45, 49, 76, 81, 217
Biotite under mesothermal conditions, Alteration of (Schwartz), 164
Birthday Gift mine, folds, Western Australia, 453
Blackett, P. M. S., correction on book by, 114
Blanchard,—., and Hall,—., on Mt. Isa ore deposit, Queensland, 892
Block diagrams, *en echelon* fold pattern, 451
fluorite, pipe deposits, 672
Block diagrams and graphic methods (review), 502
Block faults, Tajmište region, Yugoslavia, 19
Bloem, J., Kröger, F., and Vink, H., on galena, 760
Bloom, H., on dithizone, 878
Bloss, F. D., and Steiner, R. L., abstract by, 916
Bobrievich, A. P., *et al.*, review of book by, 220
Böse, E., on limestone, Parral district, Mexico, 1009
Books received, 115, 226, 358, 503, 603, 769, 905
Borates, mineralogy (abstract), 925
Borax, 925

Borchert, H., on chalcopyrite, 694
on coal, 830
on Cu-Fe-S system, 439
on fluorine, 665
on iron ores, 15
Bornite, 316, 404, 408, 598, 602, 874, 1039, 1040
Boulder batholith, Montana, and its possible significance to ore deposition, Deuteric alteration of some aplite-pegmatites of the (Neuerburg), 287
Boutwell, J. M., on biotite, 169
Bowen, N. L., on lime-silicate minerals, 693
on Rosenbush Order of Crystallization, 215
on silica, 686
on solutions, 237
Bowen, N. L., and Tuttle, O. F., on albite-water system, 343
on water, 293
Bowie, S. H. U., and Horne, J. E. T., on fluorescence, 300
Boxwork, fluorite, 673
western U.S., 673, 675, 684
Boydell, H. C., on pyrite, 991
Bradford, H. R., spectroscopic analyses by, 478
Bradley, J., on Lyell shear, 370
Bradley,—, and Grim,—, on montmorillonite, 591
Bragg, W. H., and Gibbs, R. E., on quartz, 251
Bramlette, M. N., and Posnjak, E., on ptilolite, 31
Brangle ore, 146
Branner, J. C., on Jacobina series, Brazil, 419
Brannerite, 490, 887
Brass, 162
Braunite, 583, 584, 585, 592
Brauns, F. E., on lignin, 824
Bravoite (?), 432, 446
Brazil, Uranium-bearing auriferous reefs at Jacobina (Bateman), 417
Jacobina conglomerates (discussion), 492
Breccias, fluorite deposits, western U.S., 672, 674, 684
porphyries, western U.S., 806
porphyry-conglomerate, Quebec, 745, 747
Tennessee, Jefferson City zinc mine (abstract), 921
Breger, I. A., *Design of simple punched card systems with reference to geochemical problems*, 325–338
Geochemistry of coal, 823–841
on humic substances, 824
Breger, I. A., and Deul, M., on uranium, 833
Breger, I. A., and Schopf, J. M., on germanium, 832
Breger, I. A., and Whitehead, W. L., on lignin, 825
Breger, I. A., Deul, M., and Meyrowitz, R., on uranium, 833
Breger, I. A., *et al.*, on uraniferous lignite, 833
Breislak, S. on vacuoles, 239
Brewster, D., on inclusions, 239
Bridgman, P. W., on shearing of organic substances, 827
Brillouin zone theory (discussions), 759, 762
Brines, inclusions in sulfides, Tri-State district (abstract), 929
British Columbia, natural resources (review), 502
British Commonwealth, raw materials (review), 767
Broadbent, S. R., and Shaw, A. J., on vitrinite, 106
Brock, B. B., Nel, L. T., and Visser, D. J. L., on uraninite, 889
Broderick, A. T., review by, 626
Broderick, T. M., discussion by, 1042
Broderick, T. M., Hohl, C. D., and Eidemiller, H. N., on copper, 1044
Brønsted, H. V., review of book by, 627
Brongersma-Sanders, M., on fracture zones, 619
Brotzen, O., discussion by, 489
on uraniferous conglomerates, 887
Brown, H. E. Monnett, V. E., and Stovall, J. W., review of book by, 629
Brown, J. K., and Hirsch, P. B., on coal, 829
Brown, J. S., on magnetite, 137
Brown, P. M., *The relation of phosphorites to ground water in Beaufort County, North Carolina*, 85–101
Brownell, G. M., abstract by, 916
Bruce, E. L., on replacement, 991
Brummer, J. J., *Supergene copper-uranium deposits in northern Nova Scotia*, 309–324
discussion of paper by, 1038
on uranium, 1038
Brunett, C. E., Spence, D., and Risi, J., on peat, 825
Bubleinikov, F. D., review of book by, 1056
Bucher, W. H., on stereographic method, 278
Buckley, H. E., on crystal growth, 253
Buddington, A. F., on titaniferous magnetite, 781
Buddington, A. F., Fahey, J. J., and Vlisidis, A., on titania, 779
Buddington, A. F., with Balsley, J. R. *Iron-titanium oxide minerals, rocks, and aero-magnetic anomalies of the Adirondack area, New York*, 777
Bültemann, H. W., on fluorescence, 300
Buerger, A. M., on lineage surfaces, 249
Buerger, M. J., on mineralizers, 293
Buerger, N. W., on sphalerite, 694
Bunn, C. W., on concentration gradients, 253

Burch, O. G., on glass stability, 254
Burchard, E. F., on fluorspar, 665
Burckhardt, C. E., on shale, Parral district, Mexico, 1009
Burton, L. R., on uranium, 833
Butler, B. S., on alteration, 58
Butler, B. S., *et al.*, on granite, 1044
Butler, J. R., on V, Cr, and Ni, 834
Butts, C., on Elbrook formation, Va., 731

Cady, G. H., *Coal geology and the coal industry*, 511–520
on coal geochemistry, 823
Calcite, 13, 27, 82, 152, 166, 167, 170, 243, 247, 248, 582, 593, 655, 669, 974, 977, 1017
Calcrete, 580
California, bentonite deposit, A contribution on the Hector (Ames, Sand, and Goldich), 22
geochemical exploration, Darwin mines (abstract), 913
mineral resources (review), 352
ore deposits and porphyries, 810
quartz, analyses of inclusions, 236, 261
Calvache, A., on pyrite, 968
Cambrian, Maryland, limestone aquifers, 729, 731
Cameron, E. N., and Emerson, M. E., abstract by, 917
Cameron, E. N., Rowe, R. B., and Weis, P. L., on solutions, 239
Cameron area, uranium in soils, Ariz., 200
Campbell, H. D., on cassiterite, 66
Campbell, I., review by, 352
Campbell, J. D., *En echelon folding*, 448–472
on structure, Kalgoorlie gold field, Western Australia, 470
Canada, Porphyritization in Destor and Duparquet Townships, Abitibi West County, Quebec (Graham), 737
mineral resources, western Canada (review), 502
Proterozoic (review), 112
Cape Province, South Africa, Manganese ores from the Kuruman district, (Frankel), 577
Carbon dioxide, iron mineral stability effects, 131
Carbonate, 12, 170, 248
Carboniferous, Narragansett basin, R. I., 565
Nova Scotia, 311, 312
Card systems with reference to geochemical, problems, Design of simple punched (Breger), 325
Carey, C. L., and Waksman, S. A., on bacteria, 613
Carey, S. W., on Lyell shear, 370
Carstens, C. W., on pyrite, 992
Cary spectrophotometer, 524
Casey, R. S., and Perry, J. W., on punched cards, 325
Cassiterite-bearing veins at Irish Creek, Virginia, and their paragenetic relations, Minerals of the (Glass, Koschmann, and Vhay), 65
Castaño, J. R., and Garrels, R. M., on iron minerals, 124
Cater, F. W., on anticlines, 954
Cauwood, J. D., and Turner, W. E. S., on glass, 255
Cavinato, A., on arsenopyrite, 868
Cavinato, A., and Bianchi, A., on Bacu Locci area, Sardinia, 868
Cavinato, A., and Zuffardi, P., on fissures, 871
Cayeux,—., on phosphorites, 90
Célébonovic, S., and Grigson, G., review of book by, 115
Cellulose, 824
Cement, marble, Md., 728
Cesium, occurrence in quartz, 259
Chalard, J., on uraniferous coals, 833
Chalcedony, 31
Chalcocite, 312, 314, 316, 429, 434, 604, 1039
Chalcopyrite, 82, 316, 404, 408, 428, 432, 437, 598, 602, 694, 705, 762, 874, 932, 974, 981, 989, 1016, 1039, 1040
Chalcopyrrhotite, 441
Chamberlain, J. A., discussion by, 339
on ore bodies, 893
Chamberlin, T. C., on pitch-flat structures, 143
Chamosite, 11, 12
Chamositic iron ore deposits near Tajmište, Western Macedonia, Yugoslavia (Page), 1
Chandra, D., *Reflectance of oxidized coals*, 102–108
Chandra, D., and Bond, R. L., on vitrinite, 106
Charleworth, G. H., on pyrite, 983
Chemical analyses, ash and soil, Tenn., 916
basalt and gibbsite, Hawaii, 852
bentonite, etc., Calif., 31
beryl, Va., 78
coals, R. I., 569
fluid inclusions, 474
ground water, North Carolina, 180
iron ores, Yugoslavia, 15
marble and limestone, Maryland, 725, 730
ores, copper-uranium, Nova Scotia, 371
manganese, South Africa, 584, 590, 596
tungsten, Hong Kong, 485
phosphate oolites, 1047, 1048
phosphorites, N. C., 95
porphyry, Quebec, 742
pyrite, Cuba, 984, 985
pyrite and pyrrhotite, 556
rocks, Cuyuna district, Minn., 710
Mt. Lyell district, Tasmania, 375
Victory scheelite mine area, Nev., 52

Chemical Analyses—*Continued*
sphalerite, Colo., 697
uranium minerals, Colo. Plateau, 939
Chemical analyses of the fluid inclusions in a group of New Mexico minerals (Ames), 473
Chemical analysis of fluid-filled inclusion from minerals, Technique for the extraction and partial (Roedder), 235
Chemical character of water in the igneous and metamorphic rocks of North Carolina (LeGrand), 178
Chemical composition, coals, 103
Chemical environment of pitchblende (Miller), 521
Chert, 243, 247, 714, 715
fluid inclusions, analysis, 476
Chihuahua, Mexico, Structure of the ore deposits at Santa Barbara (Scott), 1004
Chimneys, sulfides, Gilman district, Colo., 691, 706
China, tungsten, south China, 481
Chlorine, 240
Chlorites, 81, 166, 167, 169, 258, 261, 397, 568
Influence of ionic substitution on the stability of micas and (Devries and Roy), 958
Chondrodite, 212
Chowdhury, J. K., Datta, P. B., and Ghosh, S. R., on sulfur, 834
Chromite, 389
Transvaal, Bushveld Complex, origin (abstract), 917
Chromium, substitutions in chlorites, 963
Chrysotile, 960
Cissarz, A., on chamositic ores, 4
Civran, G., and Petrascheck, W., on coalification, 828
Clappison, R. J. S., and Zani, J. A., on the Copperhead mine, Western Australia, 466
Clarke, F. W., on shales, 710
Clay minerals, 171
Clays, copper clay deposits, Tasmania, 407, 414
Clegg, K. E., on alteration of coal, 828
Clinochlore, 964
Clinoptilolite, 22, 31, 35
Clinozoisite, 83
Cloke, P. L., discussion by, 494
Cloos, E., on Beekmantown limestone, Md., 732
on lineation, 278
Coal, Geochemistry of (Breger), 823
oxidation rims, 105
pyrite replacement, Nova Scotia, 314
U.S.S.R. (review), 895
Coal and metamorphic grade of rocks of the Narragansett basin of Rhode Island, Rank of (Quinn and Glass, 563
Coal geology and the coal industry (Cady), 511
Coalification, 826
Coals, Reflectance of oxidized (Chandra), 102
Cobalt, Minas Carlota, Cuba, 967
Coffinite, 887
Cohen, A. J., and Sumner, G. G., on quartz, 250
Coleman, L. C., on gold, 986
Coleman, R. G., on iron-sphalerite geothermometer, 945
Coleman, R. G., and Delevaux, M., on Se, 599
Colemanite, 26
Collins, W. H., and Kindle, E. D., on sulfides, 996
Colloform ore deposition (reviews), 901, 902
Colloids, ore formation in veins (review), 901
Collophane, 85, 91, 110, 1047, 1048
Color, alteration zone, Monument Valley, Ariz., 646, 647
coal, 829
uranium and thorium minerals, 301
Colorado, Temperatures and depth of formation of sulfide ore deposits at Gilman (Lovering), 689
faults, Leadville area (abstract), 928
fluorite, Poncha Springs deposit, fluorine content, 479
San Juan Mtns., guidebook (review), 112
uranium, sulfur isotope ratios, 601, 606
Colorado Plateau, pitchblende, White Canyon district, 544
uranium (abstract), 922
composition and size of deposits (abstract), 923
sulfur isotope ratios, 601, 606
Colorado Plateau ores, Isotopic study of some (Miller and Kulp), 937
Columbite, 931
Columbium, Idaho, Lemhi Co. (abstract), 913, 930
Communications—
Albite porphyries as a guide to gold ore (Ward), 754
Cold acid extraction of copper from soils and sediments—A proposed field method (Canney and Hawkins), 877
Localization of ore districts (Ward), 618
Solubility product and ore precipitation (Street), 617
Study of manganese ore minerals of India (Sreenivas), 109
Concretions, Santa Barbara district, Mexico, 1010
Conglomerates, uranium deposits (discussions), 489, 492, 620, 621, 757, 887, 889, 1048
Conolly, H. J. C., on Lyell schists, 370
Contact hydrothermal alteration, 288
Continents, lineaments and ore districts (communication), 618

Conway, E. J., on lake water, 133
Copper, Colorado, Gilman district, 689
field test for (communication), 877
geochemistry, Monument Valley, Ariz.-Utah, 658
Mexico, Au-Cu, Santa Maria del Oro deposit (abstract), 918
Mt. Lyell mines, Tasmania, 367, 369
New Brunswick, Bathurst district, genesis (discussion), 623
Northern Rhodesia, Lewis mine area (discussion), 623
Nova Scotia, uranium-copper deposits (discussion), 1038
Queensland, Mt. Isa deposit (discussion), 891
U.S.S.R., Kounrad deposit (review), 894
Utah, Hideout No. 1 mine, Blanding, 949
Copperhead mine, folds, Western Australia, 466
Copper-uranium deposits in northern Nova Scotia, Supergene (Brummer), 309
Cornwall, H. R., on granite, 1044
Correlation, coal deposits and metamorphic zones, 574
uranium and gold in conglomerate (discussion), 490
Correns, C. W., on iron sulfides, 129
Corrosion, fluorite, New Mexico, 676, 684
Corvusite, 658
Courtis, W. M., on inclusions, 262
Covellite, 316, 429, 434, 598, 602
Cox, D. C., on fluorspar, Colo.-Idaho, 665
Cox, G. H., on pitch-flat structures, 143
Cox, S. H., on hectorite, 25
Craig, H., on C^{13}/C^{12}, 830
Crawford, R. D., and Gibson, R., on Gilman district, Colo., 690
Croft, W. J., on pitchblende, 526
Cronstedt, A. F., on galena, 212
Crosby, J. W., III, and Hoffman, S. R., on fluorspar, Calif., 665
Cryptomelane, 582, 584, 594, 927
fibrous cryptomelane, 588
Crystal growth, 253
Crystal structure, sulfides (discussion), 759, 762
Crystallography, diamond (review), 1056
Cuba, Banded deposits of Minas Carlota (Hill), 966
Cubanite, 428, 432, 444
Curie, J., on quartz, 250
Curie point, 778, 785, 803
Cuyuna district, central Minnesota, Titaniferous sedimentary rocks in the (Schmidt), 708
Cvijič, J., on Macedonia, 3

Dahllite, 110
Dams, engineering geology, case histories (review), 627
Lone Pine area, Ariz., 854
Dams and dam sites (review), 222
D'Arcy, G., on minerals, 300
Darton, N. H., on Bidahochi formation, Ariz., 861
Davidite, 629
Davidson, C. F., discussions by, 887, 1048
discussions of articles by, 489, 492, 620, 621, 757, 889
on Blind River uranium deposit, Ont., 889
on hydrothermal mineralization, 888
on sediments, 490
on uranium, 417
reviews by, 500, 766, 894
Davidson, C. F., and Bowie, S. H. U., on polymerization, 490
Davidson, C. F., and Ponsford, D. R. A., on sulfides, 490
on uraniferous coals, 833
Davies, W. E., on a cave, Westminster, Md., 729
Davis, J. H., abstract by, 917
Davis, R. I., abstract by, 918
Davis, S. G., *Tungsten mineralization in Hong Kong and the New Territories*, 481–488
Davy, H., on vacuoles, 239
Dechow, E., review by, 355
Decrepitation, inclusions in quartz, 263
Deicha, G., on CO_2, 266
Deicha, G., and Taugourdeau, P., on CO_2, 266
Deltombe, E., and Pourbaix, M., on hematite, 124
Density of coal, 828
Denson, N. M., *et al.*, on uranium, 833
de Oliveira, A. I., on Minas series, Brazil, 419
Derry, D. R., abstract by, 918
on gold-silver ratio, 755
Destas, A., photography by (review), 767
Desulfovibrio, 611
Deul, M., and Annell, C. S., on elements in coals, 832
Deuteric alteration of some aplite pegmatites of the Boulder batholith, Montana, and its possible significance to ore deposition (Neuerburg), 287
De Villiers, J. E., on Postmasburg manganese ores, South Africa, 593
Devonian, Catskill formation, Pa, 1038
uranium deposits (abstract), 931
Maryland, limestone aquifers, 733
Tajmište area, Yugoslavia, 6, 15
De Vore, G. W., on recrystallization, 297
Devries, R. C., and Roy, R., *The influence of ionic substitution on the stability of micas and chlorites*, 958–965
Diagrams, bomb, uranium solution, 525, 527
electrolytic cleaning cell, 242, 475
en echelon folding, 449
fluorine, geochemical cycle, 666
ionic composition, ground water, N. C., 185

Diagrams—*Continued*
iron minerals, stability fields, 130
margarite, muscovite, and paragonite, 962
metamorphic assemblages, Nairne pyritic formation, South Australia, 553
minerals and intensity of oxidation, Adirondacks, 782
openings due to fault movements, 1021
ores and Moenkopi-Shinarump contact, Holiday Mesa, Utah, 642
Owen formation, Lyell area, Tasmania, 388
paragenesis, ores, fluorspar, western U.S., 680
Mackinaw mine, Wash., 437
Minas Carlota, Cuba, 979
sulfides, Pa., 1041
zinc-lead, Ill.-Wis., 152
petrological composition of coals, 106
phase-rule diagrams and ores, 440, 443
punched card, 327
pyrite, formation temperatures, 698
reaction products of dolomite and pegmatite, 60
rock textures in mining districts, 817
solids, pressure-temperature composition models, 342
solubility of sulfides, 495
stratigraphy, Beaufort Co., N. C., 88
structural plane geometry, 273
S^{32}/S^{34} ratios, sulfides, 605
uranium content of soils, 192
x-ray spectrometer tracings, anthracite and carbon, 573
zinc-lead ore occurrences, Wis.-Ill., 144
Diamonds, crystallography (review), 1056
Siberia (review), 220
Dick, W. E., review of book by, 223
Dictionaries, English-Russian (review), 1057
Dietz, R. S., Emery, K. O., and Shepard, F. P., on glauconite, 98
Differential thermal analysis, coal, 829
Differentiation, aplites-pegmatites, 294
Digenite, 1039
Dikes, Bacu Locci area, Sardinia, 869
Canavieiras mine area, Brazil, 419
coal alteration effects, 828
Destor and Duparquet Townships, Quebec, 739
Irish Creek cassiterite area, Va., 70
Monument Valley area, Ariz.-Utah, 645
Nevada, Victory scheelite mine area, 40, 41
porphyries, western U.S., 806, 813
sandstone, Mt. Lyell district, Tasmania, 387
Santa Barbara district, Mexico, 1011
Tajmište area, Yugoslavia, 10
Discussions—
Apatite-like mineral of sediments (Lund), McConnell, 110
Classification of metalliferous provinces and deposits (Sullivan), Broderick, 1042
Facies relations in the Gunflint iron formation—A reply (Goodwin), Alexandrov, (Goodwin), 349
Geochemistry, crystal structure and mineralogy of the sulfides (Ross), Frueh, 759; (Ross), 762
Mineralogy of phosphate oolites (McConnell), Martin, 1046
Occurrence of uranium in ancient conglomerates (Davidson), Brotzen, 489; Schnellmann, 492; (Davidson), Ramdohr, 620; Adams and Pliler, 621; (Davidson), Wiebols, 757
Ore genesis—The source bed concept (Knight), Walker, 219; Chamberlain, 339; Sullivan, 493; Phillips, 622; Kierans, 623
Paragenesis of accessory minerals in igneous rocks (Moorhouse), Schermerhorn, 215
Professional ethics of geologists (Park *et al.*), Dougherty, 496
Solubility of metal sulfides in dilute vein forming solutions (Garrels), Cloke, 494
Solubility of solids in gases (Morey), Smith and Jones, 340
Source bed concept (Knight), Walpole, 890
Supergene copper uranium deposits, Nova Scotia (Brummer), McCauley, 1038
Uranium in ancient conglomerates (Davidson), (Ramdohr), Davidson, 1048
Uranium in ancient conglomerates—A reply (Schnellman), Davidson, 887
Uranium-thorium ratio in the Blind River, Ontario, uranium-bearing conglomerate (Davidson), Friedman, 889
Dithizone, 878
Diverse remnant magnetism, 790
Dolomite, 32
Dolomitization, 689, 692, 700
Donn, W. L., and Shimer, J. A., review of book by, 357
Donnay, J. D. H., on biotite, 171
Dougherty, E. Y., discussion by, 496
on synclinal structures, 755
Dreyer, R. M., Garrels, R. M., and Howland, A. L., on inclusions, 253
Drilling, copper-uranium deposits, Nova Scotia, 316, 321
graphic solutions of structures (review), 626
Kalgoorlie gold field, Western Australia, 470

Drilling—*Continued*
lead-zinc, Wisconsin, Shullsburg district, 160
Tajmište area, Yugoslavia, 10
Dryden, I. G. C., on coal densities, 829
Duck, N. W., and Himus, G. W., on arsenic, 834
Dulhunty, J. A., on metamorphism of coal, 827
Dunham, K. C., on barite, 679
Du Toit, A. L., on limestone, 593
on Witwatersrand reef, 423
Dzhaparidze, P. N., and Drakin, L. A., on fossil resin, 831

Eargle, D. H., abstract by, 919
Ebelman, J. J., on UO_3, 522
Eckel, E. C., review of report edited by, 897
Eckelmann, W. R., and Kulp, J. L., on lead isotopes, 938
Edge, A. B., on pyrite, 991
Edwards, A. B., on copper ores, 370
on Nairne pyritic formation, South Australia, 551
on replacement, 989
on tetrahedrite, 694
Edwards, A. B., and Carlos, G. C., on selenium, 405, 560
Eh control of iron minerals, 124
Electrodialysis, 254
Electrodialysis cell, 244, 245, 475
Elliott, M. A., *et al.*, on coal hydrogenation, 830
Elliptical *en echelon* fold pattern, 453
Ells, R. W., on chalcocite, 321
Emery, K. O., and Rittenberg, S. C., on sulfide, 139
Emmons, A. B., on coal, 569
Emmons, S. F., Irving, J. D., and Loughlin, G. F., on Leadville district, Colo., 821
Emmons, W. H., on fault planes, 1021
on pyrite, 993
En echelon folding (Campbell), 448
Engineering geology (review), 221
case histories (review), 627
Engineering practices and landslides (review), 897
English, G. L., and Jensen, D. E., review of book by, 1059
Enrichment, Bacu Locci sulfide deposit, Sardinia, 876
copper-uranium, Nova Scotia, 323
manganese, Kuruman district, South Africa, 595
Entel, J., on coal oxidation, 829
Entel, J., Ruof, C. H., and Howard, H. C., on lactones, 829
Epidote, 74, 169, 170, 848
Equations, angle of departure, 275
Erd, R. C., and Evans, H. T., Jr., on smythite, 130
Erd, R. C., Evans, H. T., and Richter, D. H., on smythite, 130
Erratum, Rock magnetism (Blackett), 114
Ershov, A. D., on solutions, 900
Erythrite, 429
Ethics of geologists (discussion), 496
Eugster, H. P., and Yoder, H. S., on paragonite, 554
Euler, R., *et al.*, on sulfosalts, 764
Eulite, 784
Evans, W. D., on coal, 826
Evensen, C. G., and Gray, I. B., *Evaluation of uranium ore guides, Monument Valley, Arizona and Utah*, 639–662
Experiments, *en echelon* folding, 448
inclusions, extraction and analysis, 235
isotopic analyses of galena and pitchblende, 939
micas and chlorites, stability, 958
oxidation of coal, 102
Exploration, petroleum, subsurface geology (review), 904
Exsolution, sulfides, Gilman, Colo., 694

Faber, H., on chlorides, 240
Faul, H., on lead isotopes, 938
Fault-folds, 381
Faults, Austinville zinc mine, Va., 277
Bacu Locci area, Sardinia, 867
Canavieiras mine area, Brazil, 419
Colorado, Leadville area (abstract), 928
Destor and Duparquet Townships, Quebec, 739
fluorite areas, western U.S., 668
Hector district, Calif., 22, 25, 29
Kuruman manganese district, South Africa, 581
Mt. Lyell district, Tasmania, 371, 376, 384, 392
Nevada, Victory scheelite mine area, 40, 41
New Brunswick, Bathurst ore district (discussion), 624
pitches, Shullsburg district, Wis., 155
Santa Barbara district, Mexico, 1005, 1013, 1021
Tajmište district, Yugoslavia, 1, 6, 15, 18
Texas, Karnes Co. (abstract), 919
Faust, G., Murata, K. J., and Fahey, J. J., on serpentinites, 994
Feely, H. W., and Kulp, J. L., on bacteria, 945
on hydrogen sulfide, 604
Feigel'man, Kh. E., on phosphorus in coal, 834
Feldspar, 248
Feldspathization, 49
Feldspathized granodiorite at the Victory mine, Gabbs, Nevada, Scheelite in (Humphrey and Wyatt), 38
Fenneman, N. M., on Basin and Range Province, U.S., 807
on Canyon Lands, Utah, 951

Ferguson, H. G., on Irish Creek area, Va., 69
Ferguson, H. G., and Gannett, R. W., on inclusions, 260
Ferrian ilmenite, 781, 786, 803
Ferricrete, 580
Ferrohastingsite, 783
Ferrohypersthene, 784
Fersman, A. E., review of memorial book for, 1056
Fersman, A. E., and Goldschmidt, V., review of translation by, 1056
Fersmite, 931
Fieldner, A. C., Selvig, W. A., and Frederic, W. H., on meta-anthracite, 569
Filimonova, A. A., on intergrowths, 407
Finch, W. I., on punched cards, 325, 601
Finlayson, A. M., on sulfides, 979
Finnell, T. L., and Gazdik, W. B., *Structural relations at the Hideout No. 1 uranium mine, Deer Flat area, San Juan County, Utah*, 949–957
Fischer, F., and Schrader, H., on lignin, 824
Fischer, G., on bacteria, 826
Fisher, N. H., on biotite, 171
Flaig, W., on lignin, 824
Fleischer, M., review by, 767
Fletcher, H., on copper, 310
Fletcher, J. F., analysis by, 81
Florida, apatite-like mineral in phosphorites (discussion), 110
phosphates, oolites, mineralogy (discussion), 1047
Fluid, 347
Fluid inclusions in a group of New Mexico minerals, Chemical analyses of the (Ames), 473
Fluid-filled inclusions from minerals, Technique for the extraction and partial chemical analysis of (Roedder), 235
Fluorapatite, 110, 1046
Fluorescence, uranium and thorium minerals, 300, 306
Fluorine, geochemistry, 665
Fluorite, 75, 79, 211, 407, 483, 1017
Illinois, fluid inclusions, 474
Illinois-Kentucky (abstract), 925
Fluorspar deposits in the western United States, Geologic characteristics of (Peters), 663
Folding, en echelon (Campbell), 448
low-angle movements, 16, 17
Folds, 278, 284
en echelon folds, 448
fluorite mineralization and folds, 668
Monument Valley, Ariz.-Utah, 642
Mt. Lyell district, Tasmania, 371, 376, 381, 393
ore deposits and folds (communication), 754
Santa Barbara mining district, Mexico, 1012
Shullsburg district, Wis., 142, 148, 150
Folds—*Continued*
Tajmište district, Yugoslavia, 18
titaniferous metasedimentary structural markers, 720
Foldvari, A., on uraniferous coal, 833
Formulas, hectorite, Calif., 30
iron minerals, equilibrium, 125
pitchblende formation, 530
δ_s^{34} permil ratios, 600
Forrest, J. S., Smith, A. C., and Ward, J. M., on germanium, 833
Fortesque, J. A. C., on germanium, 832
Foshag, W. F., and Woodford, A. O., on bentonite, 25
Foslie, S., on pyrite, 991
Fossils, man (review), 114
Fourmarier, P., review of book by, 769
Fox, P. P., on limestone, 864
Fractures, Bacu Locci area, Sardinia, 870
Santa Barbara district, Mexico, 1013
Shullsburg district, Wis., 150
Victory scheelite mine area, Nev., 43
France, kaolin, Brittany (review), 224
Francis, W., on coal, 830
on geochemistry, 824
Francolite, 110, 1046
Franke, N. W., *et al.*, on coal oxidation, 829
Frankel, J. J., *Manganese ores from the Kuruman district, Cape Province, South Africa*, 577–597
Franklin, R. E., on coal density, 828
on x-ray diffraction lines, 571
Fraser, H. J., on water, 655
Frederick valley, limestone aquifers, Md., 729
Friedel, R. A., on color of coal, 829
Friedel, R. A., and Queiser, J. A., on coal, 829
Friedman, G. M., discussion by, 889
Frink, J. W., review by, 221
Frondel, C., on fluorescence, 300
Frondel, C., and Hurlbut, C. S., Jr., on quartz, 241
Frondel, C., and Meyrowitz, R., on fluorescence, 300
Frondel, C., Riska, D., and Frondel, J. W., on minerals, 300
Frondel, J. W., on zeunerite, 300
Frondel, J. W., and Cuttitta, F., on fluorescence, 300
Frueh, A. J., Jr., discussion by, 759
on Brillouin zone theory, 762
on sulfides, 759
reply to discussion by, 762
Fry, W. L., on fossil plants, 318
Fuchs, W., on coal, 825
Fuels, U.S., bituminous coal industry, 512
Furman, N. H., and Watters, J. I., on uranium, 529
Fusain, 1041
Fused silica, 252
Fusinite, 826

Gabbs, Nevada, Scheelite in feldspathized granodiorite at the Victory mine (Humphrey and Wyatt), 38
Galena, 146, 604, 695, 705, 760, 764, 867, 874, 942, 943, 1016, 1039, 1040
electrical resistance (discussion), 760
inclusions, 474
Galena in pyrometasomatic deposits (Geijer), 210
Galenobismutite, 82
Gallagher, D., on dikes, 754
Galliher, E. W., on sulfide, 138
Gallium, substitution in phlogopite, 961
Gardner, D. L., on andesite, 25
Gardner, J. B., on Yorktown formation, 97
Garfias, V. R., and Chapin, R. C., on geology, northern Mexico, 1008
Garnet, 53, 484
Garrels, R. M., on sulfides, 494
on uranium, 612
on uranium oxides, 523
Garrels, R. M., and Dreyer, R. M., on sea water, 127
Garrety, M. D., and Blanchard, R., on fluorite boxwork, 674
Gases, solubility of solids in gases (discussions), 340, 348
Gaudin, A. M., and Bloecher, F. W., on quartz, 249
Gaudin, A. M., Spedden, H. R., and Laxen, P. A., on quartz, 249
Gavelin, S., on arsenopyrite, 868
Gazdik, W. B., with Finnell, T. L., *Structural relations at the Hideout No. 1 uranium mine, Deer Flat area, San Juan County, Utah*, 949
Gazizova, K. S., review of book by, 894
Geijer, P., *Galena in pyrometasomatic deposits*, 210–214
on andradite, 211
Geijer, P., and Magnusson, N. H., on central Sweden, 210
Genesis, copper porphyry ores (discussion), 1044
hectorite deposit, Calif., 27
mineralization and granitoid intrusives (review), 1050
ore-fluid (review), 900
ores, source beds (discussions), 219, 339, 493, 622, 623
pitchblende, Colorado Plateau, White Canyon district, 544
uranium, Colo. Plateau, 946
New Mexico, Laguna district (abstract), 924
Pennsylvania, Catskill formation (abstract), 932
Texas, Karnes district (abstract), 928
Geobotannical study, Monument Valley, Ariz.-Utah, 657
Geochemical exploration, California, Darwin mines (abstract), 913
manganese, Tenn. (abstract), 916
Geochemical problems, Design of simple punched card systems with reference to (Breger), 325
Geochemistry, alteration, tuff, California, 22
borates (abstract), 925
copper test (communication), 877
copper-zinc minerals, thermodynamic properties (abstract), 914
feldspathization, 57
fluid-filled inclusions, 236, 249, 258
New Mexico, 473
fluorine, 665
ground water, North Carolina, 178
iron minerals, stability, 124
phosphorites, N. C., 85, 93, 99
pitchblende, 521, 543
pyrite, chemical analyses, 984
soils, rare and dispersed elements (review), 896
sulfides (discussions), 759, 762
Mackinaw mine, Wash., 436
textbook (review), 502
uranium, Colo. Plateau (abstract), 924
Monument Valley area, Ariz.-Utah, 657
Morrison formation, (abstract), 923
New Mexico, Grants district (abstract), 932
precipitation by oil (abstract), 919
weathering (review), 1058
ZnS solubility in water (abstract), 914
zoning, Missouri, southeast Mo. (abstract), 917
Geochemistry of coal (Breger), 823
Geodynamics (review), 628
Geography, Alaska (review), 769
block diagrams and graphic methods (review), 502
Irish Creek cassiterite deposit, Va., 68
Kauai island, Hawaii, 842
Kuruman manganese district, South Africa, 579
Monument Valley area, Ariz.-Utah, 640
Mt. Lyell mining district, Tasmania, 370
Prentice-Hall atlas (review), 768
Santa Barbara district, Mexico, 1005
Tajmište district, Yugoslavia, 3
textbook (review), 904
Geography in 20th Century (reviews), 225, 501
Geologic causes for failure of Lone Pine Reservoir, east central Arizona (Kiersch), 854
Geologic characteristics of fluorspar deposits in the western United States (Peters), 663
Geological history, Lone Pine reservoir area, Ariz., 864
Minas Carlota district, Cuba, 998
Mt. Lyell district, Tasmania, 372
Santa Barbara district, Mexico, 1015
Victory scheelite mine area, Nev., 54

Geological maps, Castle Hayne and Yorktown formations, N. C., 87
Destor and Duparquet Townships, Quebec, 740
Hector bentonite deposit, Calif., 24
Hong Kong, 482
Hoskinnini tongue, Utah, 953
Jacobina region, Brazil, 418
Keystone Mtn. fluorite area, Idaho, 669
Kuruman district, South Africa, 578
limestone aquifers, Md., 723
Lone Pine reservoir area, Ariz., 860
Minas Carlota district, Cuba, 969
Mt. Lyell mining district, Tasmania, 384
Nairne pyritic formation, South Australia, 547
Narragansett basin, R. I., 564
North range, Cuyuna, Minn., 712
Nova Scotia, northern Nova Scotia, 310
Panther Run, Va., 70
Queenstown, Tasmania, 373
Russell quadrangle, N. Y., 800
Santa Barbara district, Mexico, 1007
Tajmište area, Yugoslavia, 6
Victory scheelite mine area, Nev., 41
Geologists and professional ethics (discussion), 496
Geology, Alaska (review), 769
aplite-pegmatites, Boulder batholith, Mont., 289
Arctic, Soviet Arctic (review), 766
copper-uranium, northern Nova Scotia, 311
Destor and Duparquet Townships, Quebec, 739
Hector bentonite deposit, Calif., 24
Hideout mine, Blanding, Utah, 951
igneous and metamorphic terranes, N. C., 179
India (review), 501
Neyveli area, 920
Irish Creek, Va., 69
Jacobina region, Brazil, 419
kaolin deposits, Brittany, France (review), 224
Kauai island, Hawaii, 844
Kuruman district, South Africa, 579
Lone Pine Reservoir area, Ariz., 857
Minas Carlota pyrite district, Cuba, 971
Nairne pyritic formation, South Australia, 546
phosphorites, Beaufort Co., N. C., 86
potash and salt (review), 1060
Santa Barbara district, Mexico, 1009
Shand memorial volume (review), 113
Shullsburg district, Wis., 141
subsurface geology in oil exploration (review), 904
textbooks (reviews), 629, 904, 1059
U.S.S.R., Kola Peninsula (review), 1058
Vermont, East Barre area (review), 355
Victory scheelite mine, Nev., 40
Geology and metamorphism of the Nairne pyritic formation, a sedimentary sulfide deposit in South Australia (Skinner), 546
Geology and the coal industry, Coal (Cady), 511
Geology of the Mt. Lyell mines, Tasmania (Wade and Solomon), 367
Geophysical prospecting, electrical methods (review), 356
magnetic anomalies and lithology, 793
Monument Valley area, Ariz.-Utah, 656
Geophysics, temperatures during filling of inclusions, 478
Georgia, Centerville area, structural section, 284
Geosynclines, Kanmantoo Group, South Australia, 546
Tasmania, 372, 374
Geotechnics and engineering geology (review), 221
Germanium, 832
Germany, rare gases in Ruhr coals, 835
Ghana (Gold Coast), auriferous conglomerates (discussion), 887
manganese, Nsuta deposit (abstract), 927
Gibbsite on the island of Kauai, Hawaiian Islands, Occurrence of (Abbott), 842
Giletti, B. J., and Kulp, J. L., on radon leakage, 945
Gill, E. D., on Eldon group, Tasmania, 378
Gill, E. D., and Banks, M. R., on Eldon group, Tasmania, 378
Gill, J. E., review of book edited by, 112
Gillerman, E., on fluorspar, Texas-N. Mex., 665
Gillet, A., on coal, 825
Gillet, A., and Urlings, J., on lignin, 825
Gillson, J., on fluorspar, 665
Gilluly, J., on biotite, 169
on granite, 59
Gilman, Colorado, Temperatures and depth of formation of sulfide ore deposits at (Lovering), 689
Ginter, R. L., on sulfate, 139
Glaciation, Queenstown region, Tasmania, 379
Glass, H. D., on coal rank, 829
Glass, H. D., with Quinn, A. W., *Rank of coal and metamorphic grade of rocks of the Narragansett basin of Rhode Island*, 563
Glass, J. J., Koschmann, A. H., and Vhay, J. S., *Minerals of the cassiterite-bearing veins at Irish Creek, Virginia, and their paragenetic relations*, 65–84
Glenn, R. A., and Olleman, E. D., on functional groups, 830
Glossary, coal petrology, 519
Glow curves and peaks, 701
Goddard, E. N., on fluorspar, Colo., 665
Goddard, E. N., *et al.*, on plunge, 278

Gold, 429, 435, 446, 490, 620, 705, 874
albite porphyries and gold deposits (communication), 754
Brazil, Jacobina reefs, 417, 421
conglomerate deposits (discussion), 887
Mexico, Santa Barbara district, 1016
Santa Maria del Oro deposit (abstract), 918
Minas Carlota, Cuba, 967
Mt. Lyell mines, Tasmania, 367, 369
North Carolina, Gold Hill area, ground water, 182, 187
Northern Rhodesia, Matala and Dunrobin mines (discussion), 623
porphyry deposits, Abitibi West County, Quebec, 738, 752
pyrite-gold deposits, 986
South Africa, Witwatersrand, origin and uranium minerals (review), 225
Western Australia, folded deposits, 453
Gold ore of the Mackinaw mine, Snohomish County, Washington, Nickel (Milton and Milton), 426
Gold-electrum, 435
Gold-silver ratios (communication), 755
Goldich, S. S., analyses by, 31
Goldich, S. S., with Ames, L. L., Jr., and Sand, L. B., *A contribution on the Hector, California, bentonite deposit*, 22
Goldman, M. I., and Tracey, J. I., Jr., on resilication, 848
Goldring, M. S., review of book by, 114
Goldschmidt, V. M., on coal ash, 832
on fluorine, 665
on sulfide layer, 997
Goldstein, R. F., review of book by, 1059
Golovanov, N. G., and Brovchinskii, I. V., on wax, 830
Goodwin, A. M., on feldspar, 350
reply to discussion, 349
Gossans, Nairne pyritic formation, South Australia, 549
Graham, J. W., on magnetic orientation, 804
Graham, J. W., Buddington, A. F., and Balsley, J. R., on magnetostriction, 803
Graham, R. B., *Porphyritization in Destor and Duparquet Townships, Abitibi West County, Quebec, Canada*, 737–753
Granites, accessory minerals (discussion), 218
Adirondacks, magnetic properties, 786, 796
Hong Kong and south China, 481
Vermont, East Barre area (review), 356
Granitoid texture, 809
Granodiorite at the Victory mine, Gabbs, Nevada Scheelite in feldspathized (Humphrey and Wyatt), 38
Grant, U. S., on pitch-flat structures, 143
Graphic granite, 290
Graphitization of coal, 571
Graphs, analyses, pyrite, Cuba, 985
assays, Holiday Mesa channel, Utah, 660
coal composition, 105
copper-uranium content of ores, Nova Scotia, 318
electrodialysis cell current flow, 477
histograms, phosphorites, N. C., 93
magnetite content and magnetic susceptibility, 789
micas, decomposition temperatures, 960
P-T for sulfides, 559
soils, copper content determinations, 884
solutional thinning of limestone and mineralization, 159
sphalerite, FeS content, 696
sulfur isotope fractionation and temperature, 611
thermal analysis, cryptomelane, South Africa, 592
uranium in soils, Cameron, Ariz., 204
uranyl ferrocyanide, spectral absorption, 524
volume of spherical inclusions, 238
x-ray spectrometer tracing, minerals, R. I., 568
Graton, L. C., on mineralization, 872
on replacement, 991
Graton, L. C., *et al.*, on quartz, 980
Gray, I. B., with Evensen, C. G., *Evaluation of uranium ore guides, Monument Valley, Arizona and Utah*, 639
Green, J., and Kerr, P. F., on uranium, 686
Greenland, sulfides, Igdlokunguak deposit, 438
Gregory, H. E., on Deer Flat area, Utah, 951
on Monument Valley, Ariz.-Utah, 640
Gregory, J. W., on Mt., Lyell district, Tasmania, 370
Greisen, 74
tungsten deposits, Hong Kong, 483
Greisenization, Irish Creek cassiterite deposit, Va., 65
Griggs, D., on limestone, 704
Grigor'ev, M. Yu., on durain, 831
Grigor'ev, S. M., on coal, 831
Grim, R. E., and Bradley, W. F., on illites, 962
Grip, E., and Ödman, O. H., on polymerization, 490
Groenewege, M. P., Schuyer, J., and van Krevelen, D. W., on dielectric constant of coal, 830
Grogan, R. M., on collapse structures, Ill., 677
Grogan, R. M., and Shrode, R. S., on inclusions, 474
Gross, J., on quartz, 249
Gross, W. H., on solutions, 989
Ground water, lead-uranium, solution and migration, 946

Ground water in Beaufort County, North Carolina, The relation of phosphorites to (Brown), 85
Grout, F. F., on granite, 1045
on ore, 990
Grout, F. F., *et al.*, on Precambrian, Cuyuna district, Minn., 711
Gruner, J. W., abstract by, 919
on cryptomelane, 590
on feldspar, 748
on hydrogen sulfide, 614
on pitchblende, 522
on uranium, 323
translation by, 620
Gruner, J. W., and McConnell, D., on francolite, 110
Gruner, J. W., and Smith, D. K., Jr., on "yellow ores," 658
Gruner, J. W., Fetzer, W. G., and Rapaport, I., on Marysvale area, Utah, 207
Gruner, J. W., Gardiner, L., and Smith, D. K., Jr., on hydromicas, 650
on minerals, 201
on "yellow ores," 658
Gruner, J. W., Rosenzweig, A., and Smith, D. K., Jr., on uraninite, 658
Grutt, E., on uranium, 613
Gushkin, G. G., and Prikhid'ko, P. L., on fluorite, 474

Haber, D., and Bergen, S. W., review of book edited by, 767
Haber, E., on schist, 396
Haberlandt, H., Hernegger, F., and Scheminzky, F., on fluorescence, 300
Hadzi, D., and Novak, A., on sulfur, 834
Hagerstown valley, limestone aquifers, Md., 731
Hall, G. M., on Waynesboro formation, Md., 731
Hamilton, W. B., on plutons, 808
Hammond, D. L., Chi, A. R., and Stanley, J. M., on quartz, 251
Hanson, G., on sulfides, 979
Happ, S. C., abstract by, 920
Harder, E. C., on bauxite, 844
Harder, E. C., and Johnston, A. W., on slate, 710
Harker, R. I., and Tuttle, O. F., on quartz, 693
Harned, H. S., *et al.*, on uranium, 523
Harrell, M. A., and Eckel, E. B., on sinkholes, 863
Harris, P. M., and Waring, C. E., on quartz, 251
Harrison, J. B., on resilication, 848
Harvey, H. S., *et al.*, on uranium, 526
Harvey, H. W., on carbon dioxide, 135
Harvey, R. D., on electrical resistance, 760
Hashimoto, S., on vitrite, 832
Hatch, F. H., Rastall, R. H., and Black, M., on iron sulfides, 129
Haun, J. D., and LeRoy, L. W., review of book edited by, 904
Hauser, E. A., and Reynolds, H. H., on montmorillonites, 26
Hausmannite, 583, 585, 594
Hawaiian Islands, Occurrence of gibbsite on the island of Kauai (Abbott), 842
Hawkes, H. E., and Bloom, H., on dithizone, 878
Hawley, J. E., on elements in coal, 832
on pyrite, 986
Hawley, J. E., Colgrove, G. L., and Zurbrigg, H. F., on Fe-Ni-S system, 439
Haycock, M. H., on gold, 986
Hayes, A. O., on iron ores, 15
Head, R. E., on salt crystals, 474
Head, W. B., III with Holland, H. D., Witter, G. G., Jr., and Petti, R. W., *Use of leachable uranium in geochemical prospecting on the Colorado Plateau.* II., 190
Headlee, A. J. W., and Hunter, R. G., on coal ash, 832
Hector, California, bentonite deposit, A contribution on the (Ames, Sand, and Goldich), 22
Hectorite, 25
Hedvall, J., on uranium, 536
Hegemann, F., on pyrite, 994
Heinrich, E. W., *et al.*, abstract by, 930
Hematite, 80, 124, 138, 389, 584, 788, 794, 803
titaniferous hematite, 778, 803
Hematitization, 403
Herdsman, W. H., analyses by, 52
Hernandez Sanchez, M. S., on Parral mining district, Mexico, 1008
Herrmann, L. A., on Stone Mtn., Ga., 284
Hess, F. L., and Hess, Eva, on Irish Creek area, Va., 69
Hess, H. H., on serpentinization, 991
Hessite, 695, 705
Heulandite, x-ray diffraction pattern, 32
Hewett, D. F., Stone, J., and Levine, H., on fluorescence, 300
Heyl, A. V., Jr., and Agnew, A. F., on ore bodies, 143
Hickok, W. O., on minerals, 996
Hidden, W. E., on quartz, 236
Hideout No. 1 uranium mine, Deer Flat area, San Juan County, Utah, Structural relations at the (Finnell and Gazdik), 949
Hill, P. A., *Banded pyrite deposits of Minas Carlota, Cuba,* 966–1003
Hillebrand, W. F., on UO_2, 522
Hills, C. L., on Lyell schists, 370
Hills, C. L., and Carey, S. W., on schist, 396
Hilt, C., on coalification, 827
Hinds, N. E. A., on Kauai island, Hawaii, 844
Hiskey, C. F., on uranium, 540

History, Lone Pine reservoir, Ariz., 855
Minas Carlota pyrite mines, Cuba, 968
mining, Lyell area, Tasmania, 408, 409
Mt. Lyell mines, Tasmania, 369
ore deposit study in U.S.S.R. (review), 899
Santa Barbara mining district, Mexico, 1015
tungsten mining, Hong Kong, 482
uranium extraction and mining, South Africa (review), 225
Hoehne, K., on concretions, 831
on magnetite, 13
Höltje, R., and Beckert, J., on sulfides, 494
Holland, H. D., *et al.*, on leachable uranium anomalies, 201
Holland, H. D., Witter, G. G., Jr., Head, W. B., III, and Petti, R. W., *The use of leachable uranium in geochemical prospecting on the Colorado Plateau. II. The distribution of leachable uranium in surface samples in the vicinity of ore bodies*, 190–209
Holly, E. D., and Montgomery, R. S., on coal oxidation, 829
Holman, R. H. C., on copper 879
Holmes, A., on crystallization, 486
Holmes, A., and Cahen, L., on auriferous conglomerates, 887
Holmes, S. W., on brannerite, 490
Hong Kong and the New Territories, Tungsten mineralization in (Davis), 481
Horne, J. E. T., on fluorescence, 300
Horses, Mexico, Santa Barbara district, 1024
Horstman, E. L., on quartz, 250
Horton, L., on coal densities, 829
Horwood, H. C., on gold-silver ratio, 755
Hospers, J., on lava flows, 802
Hot springs, Hector district, Calif., 22
Hotchkiss, J., on arsenopyrite, 82
Hovey, E. O., on geology, northern Mexico, 1008
Howe, E., on quartz, 262
Huber, N. K., *The environmental control of sedimentary iron minerals*, 123–140
Huber, N. K., and Garrels, R. M., on iron minerals, 124
Huggard, E. M., translation by, 627
Humbert, R. P., and Shaw, B., on hectorite, 35
Hume-Rothery, W., on electrons, 759
Humphrey, F. L., and Wyatt, M., *Scheelite in feldspathized granodiorite at the Victory mine, Gabbs, Nevada*, 38–64
Huntjens, F. J., and van Krevelen, D. W., on coal reflectance, 828
Hurst, M. E., on quartz, 980
Hutchinson, G. E., on guano, 110
Hutton, C. O., on fluorescence, 300
Hydrocarbons, fossil (coal) resin, 831
Hydrogenation of coal, 830
Hydrogeology (review), 769
Hydromicas, 398
Hydrothermal alteration, 288
Hydrotroilite, 560

Ibach, R., on chalcopyrite, 981
Idaho, fluorspar, Keystone Mtn., 668
niobium-rare earths, Lemhi Co. (abstract), 930
rutile deposits, Lemhi Co. (abstracts), 913
Iddingsite, 848, 849
Identification tables for uranium and thorium minerals (Volborth), 300
Igneous and metamorphic rocks of North Carolina, Chemical character of water in the (LeGrand), 178
Igneous rocks, accessory minerals, paragenesis (discussion), 215
Adirondacks, magnetic properties, 786, 796
alnöite, Quebec, Oka area (abstract), 926
aplite pegmatites, Boulder batholith, Mont., 287
Colorado, Leadville area (abstract), 928
Cuyuna district, Minn., 716
Destor and Duparquet Townships, Quebec, 737, 739
eruptive rocks (review), 1057
granitoids and mineralization (review), 1050
Hong Kong and south China, 481
Irish Creek area, Va., 73
Kauai Island, Hawaii, 844, 848
Lake Superior region (discussion), 1044
Lone Pine reservoir area, Ariz., 859
Monument valley area, Ariz.-Utah, 644
Mt. Lyell region, Tasmania, 374
pegmatites and igneous rocks (review), 899
Santa Barbara district, Mexico, 1010
tufolavas (review), 1058
Victory scheelite mine area, Nev., 45
Illinois, fluorspar (abstract), 925
Illinois zinc-lead district, Factors controlling the localization of ore deposits in the Shullsburg area, Wisconsin (Reynolds), 141
Ilmenite, 73, 220, 778, 786, 794, 803, 851
Ilmenomagnetite, 778, 792
Inagaki, M., on durite, 832
Inclusions, fluid inclusions, 699
fluorite, inclusions, 679
granodiorite, Nev., 45
sulfides, Ti-State district (abstract), 929
Inclusions from minerals, Technique for the extraction and partial chemical analysis of fluid-filled (Roedder), 235
Inclusions in a group of New Mexico minerals, Chemical analyses of the fluid (Ames), 473

India, cryptomelane, 590
ground water, Neyveli area, 920
manganese, ores (communication), 109
mineral industry (review), 501
mineral resources, Madhya Pradesh (review), 356
Induced magnetization, 785, 787
Industry, Coal geology and the coal (Cady), 511
Infrared absorption and coal structure, 829
Ingerson, E., on geothermometry, 693
on solutions, 237
Intergrowths, chalcopyrite and bornite, Tasmania, 407
orthoclase and quartz, 487
Intergrowths and microintergrowths, 780
Ionic substitution on the stability of micas and chlorites, Influence of (Devries and Roy), 958
Ipatieff, V. N., and Muromtsev, B., on UO_2, 522
Irish Creek, Virginia, and their paragenetic relations, Minerals of the cassiterite-bearing veins at (Glass, Koschmann, and Vhay), 65
Iron, Minnesota, Cuyuna district, iron formations, 713
Gunflint formation (discussion), 349
Northern Rhodesia, Lusaka-Mumbwa district (discussion), 623
U.S.S.R., Krivoi Rog basin (review), 894
Iron minerals, The environmental control of sedimentary (Huber), 123
Iron ore deposits near Tajmište, Western Macedonia, Yugoslavia, Chamositic (Page), 1
Iron-titanium oxide minerals, rocks, and aero-magnetic anomalies of the Adirondack area, New York (Balsley and Buddington), 777
Irving, E. M., and Cruz, D. P., on sulfides, 979
Isachsen, Y. W., and Evensen, C. G., on Shinarump formation, 196
Isotopes, sulfur, Minas Carlota, Cuba, 994
uranium deposits, Colo. Plateau (abstract), 924
Isotopes and the origin of sandstone-type uranium deposits, Sulfur (Jensen), 598
Isotopic study of some Colorado Plateau ores (Miller and Kulp), 937
Italy, Lead-arsenic-sulfide ore deposit of Bacu Locci, Sardinia (Zucchetti), 867
Ivankin, P. F., review of book by, 895
Ivanov, S. N., on pyrite, 983

Jackson, C. T., on coal, 569
Jacobina, Brazil, Uranium-bearing auriferous reefs at (Bateman), 417
Jacobsite, 583, 588
James, H. L., on carbon dioxide, 132
on magnetite, 13
Jeffery, M., *et al.*, on coal, 830
Jenkins, O. P., and Wright, L. A., review of bulletin by, 352
Jenney, W. P., on pitch-flat structures, 143
Jensen, M. L., *Sulfur isotopes and the origin of sandstone-type uranium deposits*, 598–616
on description of specimens, 606
on iron sulfides, 945
Jicha, H. L., Jr., on arsenopyrite, 868
Joffe, A. F., on quartz, 251
Joints, 296
Lone Pine reservoir area, Ariz., 862
Monument Valley, Ariz., 197
Utah, Hideout No.1 mine, Blanding, 949, 951
Victory scheelite mine area, Nev., 45, 62
Jonas, A. I., and Stose, G. W., on marble, Md., 728
Jones, P. H., and Subramanyam, V., abstract by, 920
Jones reductor method for uranium, 523
Joralemon, I. B., on brecciation, 673
Jurassic, Monument Valley area, Ariz., 643

Kaemmererite, 963
Kalgoorlie district, folds, Western Australia, 455, 470
Kalyuzhny, V. A., on solutions, 239
Kanehara, N., on ore deposits, 988
Kania, J. E. A., on sulfides, 979
Kano, H., on pyritization, 990
Kaolin, 847, 850
Kaolinite, 168, 169, 171, 960
Karsulin, M., and Stubican, V., on montmorillonites, 26
Katchenkov, S. M., on germanium, 832
Katz, J. J., and Rabinowitch, E., on UO_2, 522
Kauai, Hawaiian Islands, Occurrence of gibbsite on the island of (Abbott), 842
Kawai, N., Kume, S., and Sasajima, S., on magnetization, 802
Kazakov, A. V., on phosphate, 96
Keith, M. L., and Tuttle, O. F., on quartz, 249
Keller, W. D., on alumina, 850
Kelley, V. C., on ground water, 946
Kellum, L. B., on geology, northern Mexico, 1008
Kelly, W. C., *et al.*, abstract by, 921
Kendall, D. L., abstract by, 921
Kennedy, G. C., on inclusions, 699
Kentucky, fluorspar (abstract), 925
Keppler, M. R., and Wyant, D. G., on uranium ores, 938
Kerr, P. F., on biotite, 169
on hectorite, 26
on sulfides, 599

Kerr, P. F., and Cabeen, C. K., on resistivity of sulfides, 763
Kerr, P. F., and Cameron, E. N., on zeolite, 35
Kerr, P. F., and Green, J., on illite, 171
Kerr, P. F., *et al.*, on biotite alteration, 167
Kessler, L., on UO_2, 522
Keys, M. R., on quartz, 980
Khitarov, N. I., and Rengarten, E. V., on calcite, 262
Khlopin, V. G., review of reprints by, 1057
Kierans, M. D., discussion by, 623
on Santa Barbara mining district, Mexico, 1006
Kiersch, G. A., *Geologic causes for failure of Lone Pine Reservoir, east central Arizona*, 854–866
on Lone Pine reservoir, Ariz., 855
Kiersch, G. A., and Hughes, P. W., on sinkholes, 862
Kimberlite, 220
King, L. H., and Whitehead, W. L., on chemical structure of coals, 829
King, P. B., on Parral mining district, Mexico, 1008
King, R. E., on geology, northern Mexico, 1008
Kinney, C. R., and Ockert, K. F., on oxidation of coal, 829
Kirchheimer, F., on fluorescence, 300
Kitazaki, U., on coalification, 826
Kitson, A., and Felton, W. J., on alluvial concentrates, 888
Kleeman, A. W., and Skinner, B. J., on Kanmantoo Group, South Australia, 546
Kleeman, A. W., and White, A. J. R., on Kanmantoo Group, South Australia, 546
Klepper, M. R., and Robertson, F., on Boulder batholith, Mont., 289
Klimov, B. K., on thermal analysis of coals, 829
Knight, C. L., discussions of paper by, 219, 339, 493, 622, 623, 890
on ore genesis, 493
Knopf, A., on plutons, 808
Knopf, E. B., and Jonas, A. I., on marble, 725
Knox, A. S., on Wamsutta coal flora, R. I., 565
Knutson, R. M., *Structural sections and the third dimension*, 270–286
Kober, L., on tectonics, 4
Koch, G. S., on Parral mining district, Mexico, 1008
Koczy, F. F., *et al.*, on uranium, 490
Königsberger, J., Muller, W. J., on salts, 240
Koritnig, S., on fluorine, 665
Korzhinskii, D. S., on metasomatic processes (review), 902
Kosanke, R. M., on bacteriostatic substances, 826
Koschmann, A. H., Glass, J. J., and Vhay, J. S., on Irish Creek, Va., 67
Koschmann, A. H., with Glass, J. J., and Vhay, J. S., *Minerals of the cassiterite-bearing veins at Irish Creek, Virginia, and their paragenetic relations*, 65
Kossmat, F., on Macedonia, 3
Krenkel, E., review of book by, 628
Kreulen, D. J. W., on coal geochemistry, 824
Krieger, P., and Hagner, A. F., on maucherite, 429
Kritchevsky,—.,and Zielis,—., on gases, 349
Krumbein, W. C., and Garrels, R. M., on hematite, 124
on minerals, 13
on phosphate deposition, 97
Krynine, D. P., and Judd, W. R., review of book by, 221
Kuchin, N. D., *et al.*, review of book by, 1057
Kuellmer, F. J., Carmen, J. H., and Renault, J. R., abstract by, 931
Kuenen, P. H., on scour channels, 546
Kukharenko, T. A., on hydrogenation of coal, 830
Kullerud, G., on Fe-Ni-S system, 439
on sphalerite, 695
on sulfides, 557
Kulp, J. L., on Mica Creek pegmatite, Queensland, 892
Kulp, J. L., Ault, W. V., and Feely, H. W., on sedimentary sulfides, 606
on sulfur isotopes, 994
Kulp, J. L., Bate, G. L., and Broecker, W. S., on lead-uranium decay, 942
Kulp, J. L., Feely, H. W., and Ault, W., on S^{32}/S^{34} ratios, 605
Kulp, J. L., with Miller, D. S., *Isotopic study of some Colorado Plateau ores*, 937
Kunin, R., on uranyl ion, 523
Kunkel, W. B., on quartz, 265
Kupferbürger, W., Boardman, L. G., and Bosch, P. R., on Kuruman district, South Africa, 579
Kuruman district, Cape Province, South Africa, Manganese ores from the (Frankel), 577
Kyanite, 554

Labradorite, 848
Lacy, W. C., and Hosmer, H. L., on corrosion, 676
Ladoo, R. B., on fluorspar, 665
LaGanza, R. F., review of report by, 629
Lahee, F. H., on metamorphism, R. I., 567
Lake Superior region, ore deposits (review), 224
Lakshmanan, S., on waxes, 830

Lamar, J. E., and Shrode, R. S., on inclusions, 240
Landslides and engineering practice (review), 897
Laney, F. B., on Gold Hill area, N. C., 187
La Roque, A., review of translation by, 113
Larsen, W. P., Hartzell, T. B., and Diehl, H. S., on bacteria, 613
Lasfargues, P., review of book by, 356
Lasson, G., on Lone Pine reservoir, Ariz., 857
Latimer, W. M., on siderite, 126
on $U(SO_4)_2$, 541
Latosol, 846
Laz'ko, E. M., review of book by, 895
Leachable uranium in surface samples in the vicinity of ore bodies, The distribution of (Holland, Witter, Head, and Petti), 190
Leaching, Jacobina gold reefs, Brazil, 422
outcrops (abstract), 921
Lead, galena in pyrometasomatic deposits, 210
Mt. Isa, Queensland (discussion), 891
Mt. Lyell district, Tasmania, 413
New Brunswick, Bathurst district (discussion), 623
Utah, U. S. mine, alteration (abstract), 932
Lead district, Factors controlling the localization of ore deposits in the Shullsburg area, Wisconsin-Illinois zinc (Reynolds), 141
Lead-arsenic-sulfide ore deposits of Bacu Locci (Sardinia—Italy) (Zucchetti), 867
Leedal, G. P., on albite, 401
Legget, R. F., review by, 897
LeGrand, H. E., *Chemical character of water in the igneous and metamorphic rocks of North Carolina*, 178–189
on water, 186
LeGrand, H. E., and Brown, P. M., on Castle Hayne formation, 88
Leith, C. K., Lund, R. J., and Leith, A., on granite, 1045
Lepp, H., on melnikovite, 561
Leroy, P. G., on biotite, 169
Lesquereux, L., on coal flora, R. I., 565
Leucoxene, 74, 166, 167, 172, 708, 717, 927
Levitskii, O. D., on colloform mineralization (review), 902
Lieske, R., and Hofmann, E., on bacteria, 826
Lignin, 824
Lignite, India, Neyveli area, 920
Limestone, crushing strength, 704
solution and mineralization, Ill.-Wis., 153
thermoluminescence, 701
Limestone aquifers of Maryland (Otton and Richardson), 722
Limonite, 875
Lindgren, W., on arsenopyrite, 868
on biotite, 169
on fluorspar, 665
on hypothermal deposits, 1036
on inclusions, 262
on iron ores, 15
on mesothermal ore deposits, 693
on pyrite, 988
on uranium, 491
Lindgren, W., and Irving, J. D., on pyrite, 992
on sulfides, 979
Lindgren, W., and Ransome, F. L., on adularia, 173
on quartz, 980
Lindroth, G. T., on andradite, 212
Lineation, 278
Lissner, A., and Göbel, W., on brown coals, 831
Lithia, content in travertine, hectorite, and bentonite, Calif., 34
Lithium, occurrence in quartz, 249
Lithology, uraniferous sediments, Ariz.-Utah, 194
Lobeck, A. K., review of book by, 502
Locke, A., on brecciation, 673
on pyrite, 973
Logs (tree), Cu-U-bearing, Nova Scotia, 313, 317
uranium precipitating agent, 654
Lohman, S. W., on Tonoloway and Helderberg, limestones, 733
Lone Pine Reservoir, east central Arizona, Geologic causes for failure of (Kiersch), 854
Long, S. M., on uranium oxides, 522
Lotze, F., review of book by, 1060
Loughlin, G. F., on ore deposits, 988
Loughlin, G. F., and Behre, C. H., Jr., on minerals, 693
Loughlin, G. F., and Koschman, A. H., on breccia, 676
on Cripple Creek district, Colo., 821
Lovering, T. G., *Temperatures and depth of formation of sulfide ore deposits at Gilman, Colorado*, 689–707
Lovering, T. S., on clay minerals, 171
on Mesozoic, Colo., 702
Lovering, T. S., and Behre, C. H., Jr., on Gilman district, Colo., 690
Lovering, T. S., and Goddard, E. N., on Front Range, Colo., 682
Lovering, T. S., and Tweto, O. L., on Gilman district, Colo., 690
Lovering, T. S., *et al.*, on barite, 685
Lowther, G. K., and Bell, E. B., on Parral mining district, Mexico, 1008
Lukashev, K. I., review of book by, 1058
Lund, E. H., discussion of paper by, 110
Lyon, R. J. P., on torbernite, 307

McAnulty, W. N., on breccia, 678
McAvoy, R., analyses by, 100

McCartney, J. T., on coal, 104
McCartney, J. T., and Hofer, L. J. E., on microreflectivity of coal, 828
McCauley, J. F., abstract by, 931
discussion by, 1038
McConnell, D., discussion by, 110
discussion of a discussion by, 1046
on francolite, 110
Macdonald, G. A., on Koloa volcanics, 842
Macdonald, G. A., Davis, D. A., and Cox, D. C., on Kauai island Hawaii, 844
McDowell, J. P., on uranium reefs, Blind River, Ont., 423
Macedonia, Yugoslavia, Chamositic iron ore deposits near Tajmište, Western (Page), 1
MacGregor, A. M., on carbon dioxide, 132
MacInnes, D. A., and Longsworth, D. A., on salts of uranyl sulfate, 529
MacIntosh, A. N., review of book by, 626
MacKallor, J. A., and Bunker, C. M., abstract by, 922
McKee, E. D., on Kaibab basin, Ariz., 859
on Moenkopi formation, 645, 952
McKee, E. D., Evensen, C. G., and Grundy, W. D., on Shinarump conglomerate, 641
McKelvey, V. E., Everhart, D. L., and Garrels, R. M., on uranium, Colo. Plateau, 938
McKelvey, V. E., Swanson, R. W., and Sheldon, R. P., on Phosphoria formation, 96
Mackenzie, R. C., on cryptomelane, 592
Mackin, J. H., on iron, 297
Mackinaw mine, Snohomish County, Washington, Nickel-gold ore of the (Milton and Milton), 426
McKinstry, H. E., on a magnet, 432
on bedding, 278
on fluorspar bodies, 667
McKnight, E. T., on folds, 954
Mackowsky, M. Th., on coalification, 826
McLachlan,—, and Lazar,—, and Tonetti, L., analysis by, 590
McLaughlin, D., on copper, 980
McMath, J. C., on Coolgardie ore deposits, Western Australia, 755
Macnamara, J., and Thode, H. G., on meteoritic sulfur, 608
Macrae, J. C., on mineral content of coal, 831
Maghemite, 131, 804
Magma (review), 1051
solutions and deep processes (review), 900
Magnetic anomalies of the Adirondack area, New York, Iron-titanium oxide minerals, rocks and aero (Balsley and Buddington), 777
Magnetic susceptibility, 785
Magnetism of oxide minerals, 785
Magnetite, 11, 12, 124, 137, 173, 217, 428, 435, 446, 484, 584, 621, 777, 778, 786, 794, 803
Magnetite-hematite equilibrium, 125
Magnetization of rocks, Adirondacks, 777, 796
Magnetostriction, 803
Magnusson, N. H., on central Sweden, 210
Malachite, 317, 658
Mallory, E. C., analyses by, 697
Man, fossil man (review), 114
Stone Age (review), 115
Manganese, geochemical prospecting, Tenn. (abstract), 916
Ghana, Nsuta deposit (abstract), 927
India, ores (communication), 109
Manganese ores from the Kuruman district, Cape Province, South Africa (Frankel), 577
Manger, G. E., abstract by, 922
on marcasite, 831
Manitoba, natural resources (review), 502
Mantos, Gilman district, Colo., 690
Maps (see also Geologic maps)—
aeromagnetic maps, Adirondacks, N. Y., 799
Beaufort County, North Carolina, 86
Big Indian Wash, Utah, 191
Cuyuna district, Minn., 709
Derry and Hansonburg districts, New Mexico, 478
fluorite deposits, western U. S., 664
Gilman district, Colo., 691
Gold Hill area, N. C., 187
Hector bentonite district, Calif., 23
Hideout No. 1 mine area, Utah, 950
Irish Creek, Virginia, 67
Kauai island, Hawaii, 843
Kuruman district, South Africa, 578
Lone Pine reservoir, Ariz., 856
Minas Carlota district, Cuba, 968
Monument Valley area, Ariz.-Utah, 641
Nairne pyritic formation, South Australia, 547
Parral mining district, Mexico, 1006
Providence quadrangle, R. I., 566
Queenstown area, Tasmania, 368
Shullsburg district, Wis., 142
Tajmište district, Yugoslavia, 2
Marble, Maryland, aquifers, 725
Marcasite, 152, 154, 161, 550, 598, 601, 831
Margarite, 959, 960
Marinace, J. C., on galena, 761
Markov, F. G., and Nalivkin, D. V., review of book edited by, 766
Marks, L. Y., abstract by, 923
Marlow, G. C., and Smith, J. M., on Parral mining district, Mexico, 1008
Marmatite, 1016
Marshall, C. E., on fusinite, 826
Marshall, C. E., and Draycott, A., on coal, 834
Martin, G. W., discussion by, 1046

Martite, 784
Maryland, Limestone aquifers of (Otton and Richardson), 722
Marysvale area, uranium in soils, Utah, 207
Mason, B., on maghemite, 131
on silica, 594
review of book by, 502
Mathews, E. B., and Grasty, J. S., on marble, 728
Mathieson,—., and Wadsley,—., on cryptomelane, 591
on veins, 584
Maucher, A., on pyrite, 991
Maucherite, 428, 429
Maxwell, J. A., on cherts, 259
Mayeda cell, 599
Medwenitsch, W., on tectonics, 4
Meinzer, O. E., on springs, 727
Meinzers, 726
Meixner, H., on fluorescence, 300
Meldau, R., on mineral content of coal, 831
Mellor, J. W., on copper-nickel sulfides, 438
Melnikovite, 561
Menard, H., on fracture zones, 618
Mendelsohn, E., *et al.*, on uraninite, 889
Merlich, B. V., on pyrite, 991
Mertins, A. G., on coal, 829
Merwin, H. E., and Lombard, R. H., on Cu-Fe-S system, 439
Mesothermal conditions, Alteration of biotite under (Schwartz), 164
Messervey, J. P., on copper, 311
Metailmenite, 784
Metallogenesis, fluorspar deposits, western U. S., 682
maps, U.S.S.R., (review), 896
Metallogenetic provinces (discussion), 1042
Metallogeny (review), 1053
Metals, labile metals, 298
Metamorphic grade of rocks of the Narragansett basin of Rhode Island, Rank of coal and (Quinn and Glass), 563
Metamorphic rocks, Adirondacks, magnetic properties, 786, 796
Bacu Locci area, Sardinia, 868
Mt. Lyell district, Tasmania, 383, 396
U.S.S.R. (review), 896
Metamorphic rocks of North Carolina, Chemical character of water in the igneous and (LeGrand), 178
Metamorphism, coal, 827, 828
coal and rocks, Narragansett basin, R. I., 563
East Barre area, Vermont (review), 356
Hong Kong, 485
Irish Creek, Va., 65
Lyell area, Tasmania, 396
magnetization of rocks, Adirondacks, 778
Northern Rhodesia, Katanga system (discussion), 622
Metamorphism—*Continued*
silication, 693
Tajmište district, Yugoslavia, 16
Metamorphism of the Nairne pyritic formation, a sedimentary sulfide deposit in South Australia, Geology and (Skinner), 546
Metasomatic processes (review), 902
Metasomatism, contact metasomatism, 996
Victory scheelite mine area, Nev., 46, 49, 55
Mexico, Structure of the ore deposits at Santa Barbara, Chihuahua (Scott), 1004
Au-Cu, Santa Maria del Oro (abstract), 918
sulfides, Alistos deposit, 435
Mezentseva, E. I., on geology, Central Asia, 1054
Mica, 552
Micas and chlorites, Influence of ionic substitution on the stability of (Devries and Roy), 958
Michigan, copper, origin (discussion), 1044
dikes, magnetization, 804
Microcline, 555
Microintergrowths, 781
Miers, H. A., on crystal growth, 253
Miesch, A. T., *et al.*, abstract by, 923
Mikinčić, V., on geological map, Yugoslavia, 4
Miller, D. S., and Kulp, J. L., *Isotopic study of some Colorado Plateau ores*, 937–948
abstract by, 924
Miller, H. P., on coal geochemistry, 823
Miller, L. J., *The chemical environment of pitchblende*, 521–545
on hydrogen sulfide, 614
on uranium, 945
Milne, I. H., and Nuffield, E. W., on fluorescence, 300
Milton, C., on Mackinaw mine, Wash., 427
Milton, C., and Milton, D. J., *Nickel-gold ore of the Mackinaw mine, Snohomish County, Washington*, 426–447
Milton, D. J., with Milton, C., *Nickel-gold ore of the Mackinaw mine, Snohomish County, Washington*, 426
Minas Carlota, Cuba, Banded pyrite deposits of (Hill), 966
Mineral industry, California (review), 352
Commonwealth countries (review), 767
India (review), 501
Madhya Pradesh (review), 356
Prentice-Hall world atlas (review), 768
tin and tungsten (review), 765
U. S., bituminous coal industry, 512
Mineral resources, Africa (review), 628
California (review), 352
Canada, western Canada (review), 502
Commonwealth countries (review), 767

Mineral Resources—*Continued*
India (review), 501
Madhya Pradesh (review), 356
ore reserves, calculation (reviews), 765, 1055
Turkey (review), 768
Mineralization, Bacu Locci sulfide deposit, Sardinia, 872
colloform aggregates (review), 902
Colorado, Leadville area (abstract), 928
Copperhead mine, Western Australia, 467
fluorite, Ill.-Ky. (abstract), 925
western U. S., 684
fluorite-galena, Alamo and Portales mines, N. Mex., 477
gold, Witwatersrand beds (communication), 758
granitoid intrusives (review), 1050
Irish Creek, Va., 65
Lyell region, Tasmania, 404
Minas Carlota, Cuba, 967, 998
rare earths, Quebec, Oka district (abstract), 926
Santa Barbara district, Mexico, 1005
Santa Maria del Oro deposit, Mexico, 918
scheelite, Victory mine, Nev., 52, 62
Shullsburg area, Wis., 161
sulfides, Gilman, Colo., 689
uraninite, Witwatersrand (discussion), 888
uranium, Monument Valley, Ariz., 640
zinc-lead, Ill.-Wis., 146
Mineralization in Hong Kong and the New Territories, Tungsten (Davis), 481
Mineralizers, 293
Mineralogy, aplite pegmatites, Mont., 290
borates (abstract), 925
cassiterite deposits, Irish Creek, Va., 65, 73
Cu-Zn minerals, thermodynamic properties (abstract), 915
kaolin deposits, Brittany, France (review), 224
Mackinaw mine, Wash., 426, 429
Monument #1 mine, Ariz., 198
Nairne pyritic formation, South Australia, 549, 553
niobium-rare earths, Idaho-Mont. (abstract), 930
ores, Bacu Locci sulfide deposit, Sardinia, 873, 875
Gilman district, Colo., 691
gold (communication), 755
Lyell region, Tasmania, 404
manganese Kuruman district, South Africa, 577, 583
pyrite, Minas Carlota, Cuba, 967
uranium, Monument Valley, Ariz., 640, 658
New Mexico, Grants deposit (abstract), 932
Mineralogy—*Continued*
Radium Hill, South Australia (review), 629
phosphate oolites (discussion), 1046
pyrometasomatic deposits, Sweden, 210
rutile deposits, Lemhi Co., Idaho (abstract), 913
Santa Barbara district, Mexico, 1005, 1016
sulfides (discussion), 759, 762
textbooks (reviews), 904, 1057, 1059
tungsten deposits, Hong Kong, 481, 483
uranium, Belgian Congo, Haut Katanga (review), 767
Pennsylvania, Catskill formation 932, 1039
U.S.S.R. (review), 500
uranium and thorium minerals, 300
Minerals, Chemical analyses of the fluid inclusions in a group of New Mexico (Ames), 473
Environmental control of sedimentary iron (Huber), 123
Identification tables for uranium and thorium (Volborth), 300
Rocks, and aero-magnetic anomalies of the Adirondack area, New York, Irontitanium oxide (Balsley and Buddington), 777
Technique for the extraction and partial chemical analysis of fluid-filled inclusions from (Roedder), 235
accessory minerals in igneous rocks, paragenesis (discussion), 215
coal, mineral content, 831
magnetic minerals, 779
ores, pyrite, Minas Carlota, Cuba, 967
uranium, U.S.S.R. (review), 500
Minerals of the cassiterite-bearing veins at Irish Creek, Virginia, and their paragenetic relations (Glass, Koschmann, and Vhay), 65
Minguzzi, C., and Naldoni, K. M., on arsenic, 834
Mining, bentonite, Hector, Calif., 23
graphic solutions of structures (review), 626
manganese, Kuruman district, South Africa, 596
Mt. Lyell district, Tasmania, 408
pyrite, Minas Carlota, Cuba, 969
tungsten mining, Hong Kong, 482
Minnesota, Titaniferous sedimentary rocks in the Cuyuna district, central (Schmidt), 708
ground water, Lyon Co., (abstract), 926
iron, Gunflint formation (discussion), 349
Mississippi Valley, ore deposits type, origin (abstract), 915, 930
Mississippian, Maryland, Greenbrier formation, 734
Missouri, zoning, southeast Mo., (abstract), 917

Mitcham, T. W., and Evensen, C. G., on Shinarump conglomerate, 642
Mitchell, R. C., on serpentinization, 998
Models, veins, San Martin mine, Mexico, 1027
Moench, R. H., abstract by, 924
Montana, And its possible significance to ore deposition, Deuteric alteration of some aplite-pegmatites of the Boulder batholith (Neuerburg), 287
niobium-rare earths, Ravalli Co. (abstract), 930
Montgomery, A., on schist, 396
Montmorillonite, 82, 591, 932
Monument Valley, Arizona and Utah, Evaluation of uranium ore guides (Evensen and Gray), 639
uranium in soils, Ariz., 196
Moody, J. D., and Hill, M. J., on the Texas lineament, 618
Moore, G. W., on uranium, 833
Moorhouse, W. W., discussion of paper by, 215
Mordenite, x-ray diffraction pattern, 32
Morey, G. W., discussion of paper by, 340
on miscibility gap, 341
reply to discussion, 348
Morey, G. W., and Chen,—., on sulfate systems, 349
Morey, G. W., and Hesselgesser,—., on decomposition of systems, 349
Morocco, French, Bou Beker ore deposit, genesis (discussion), 219
Morrison, L. E., and Tanner, F. W., on bacteria, 614
Mt. Lyell mines, Tasmania, Geology of the (Wade and Solomon), 367
Mrose, M. E., on fluorescence, 300
Mudd, H. T., on fluorspar, 665
Mudstone, 312
Muessig, S., abstract by, 925
Mukherjee, B., on rare earths, 834
Mukherjee, B., and Lahiri, A., on mineral content of coal, 831
Muller, S. W., and Ferguson, H. G., on Luning formation, Nev., 40
Murthy, V. R., review of bulletin by, 355
Muscovite, 76, 79, 166, 167, 554, 568, 960
Mylonitization, 16, 17

Nackowski, M. P., abstract by, 925
Nagata, T., on magnetization, 785, 802
Nagata, T., Uyeda, S., and Ozima, M., on magnetism, 802
Nagelschmidt,—., on hectorite, 27
Nairne pyritic formation, a sedimentary sulfide deposit in South Australia, Geology and metamorphism of the (Skinner), 546
Narragansett basin of Rhode Island, Rank of coal and metamorphic grade of rocks of the (Quinn and Glass), 563
Native copper, 875
Native sulfur, 603, 607
Natural gas, Texas, Karnes Co. (abstract), 919
United States, future supplies (review), 626
Wyoming, Gas Hills anticline, 612
Nebraska, pipes, Arikaree formation, 655
Néel, L., on rock magnetism, 802
Nel, L. T., on limestone, 593
Netschert, B. C., review of book by, 626
Neuerburg, F. H., analyses by, 710
Neuerburg, G. J., *Deuteric alteration of some aplite-pegmatites of the Boulder batholith, Montana, and its possible significance to ore deposition*, 287–299
on aplite pegmatites, 288
Neuerburg, G. J., Antweiler, J. C., and Bieler, B. H., on metals, 298
Neuman, R. B., on Stones River limestone, Md., 732
Neumann, H., on differentiation, 295
Nevada, Scheelite in feldspathized granodiorite at the Victory mine, Gabbs (Humphrey and Wyatt), 38
clays, saponitic clays, 35
fluorite, Daisy mine, 672
ore deposits and porphyries, 810
New Brunswick, Bathurst copper-zinc field, source beds (discussion), 623
Newhouse, W. H., on crystals, 240, 990
on fault planes, 1021
on inclusions, 474
on synclines, 754
Newhouse, W. H., and Flaherty, G. F., on pyrite, 991
New Jersey, Edison belt, oxide minerals, 803
heulandite, x-ray study, 32
New Mexico, fluorite-uranium, Grants district, 669
ore deposits and porphyries, 810
uranium, Grants deposit (abstracts), 919, 932
Laguna district, genesis (abstract), 924
sulfur isotope ratios, 601
New Mexico, minerals, Chemical analyses of the fluid inclusions in a group of (Ames), 473
New York, Iron-titanium oxide minerals, rocks, and aero-magnetic anomalies of the Adirondack area (Balsley and Buddington), 777
New York City meeting of *Society of Economic Geologists*, Feb. 17–20, 1958, 120
Niccolite, 429, 443
Nicholls, G. D., on rock magnetization, 780
Nickel, Minas Carlota, Cuba, 967
substitution in phlogopite, 961
Nickel-gold ore of the Mackinaw mine, Snohomish County, Washington (Milton and Milton), 426

Nickell, F. A., on Lone Pine reservoir, Ariz., 857
Nicol, W., on inclusions, 475
Nicolas, J., review of memoir by, 224
Niggli, P., on immiscibility, 340
Nikolaev, V. A., on immiscibility, 341
on solutions (review), 900
review of book edited by, 896
Noda, T., and Sugiyama, S., on micas, 961
Nodular gibbsite, 847
Nöth, L., on iron, 4
Noll, W., on montmorillonites, 26
Nomographs, alignment drawing for angle of departure, 274
Nontronite, 80, 83
Nopcsa, F., on tectonics, 4
Norman, G. W. H., and Bell, W. A., on Cumberland basin, Nova Scotia, 312
North Carolina, Chemical character of water in the igneous and metamorphic rocks of (LeGrand), 178
Relation of phosphorites to ground water in Beaufort County (Brown), 85
Northern Rhodesia, copper, source beds (discussion), 622
Northern Territory, Rum Jungle uranium deposit (discussion), 892
Nova Scotia, Supergene copper-uranium deposits in northern (Brummer), 309
copper-uranium deposits (discussion), 1038
mordenite, x-ray study, 32
Nuffield, E. W., and Milne, I. H., on fluorescence, 300

Occurrence of gibbsite on the island of Kauai, Hawaiian Islands (Abbott), 842
Oceans, currents and phosphorite formation, 96
Ode, W. H., and Selvig, W. A., on waxes, 830
Oechsner de Connick, F. W., on UO_3, 522
Oedman, O. H., on galena, 213
Oelsner, O., Freiberg,—., and Peukert, E., review of book translated by, 765
Officer, G., Balfour, L., and Hogg, E. G., on schist, 396
Oftedahl, C., on pyrite, 995
Oikawa, H., *et al.*, on germanium, 833
Ontario, uranium, Blind River deposits, 423; (abstract), 918
thorium-uranium ratios (discussion), 889
Oolites, chamosite, 1, 11, 12
phosphate, mineralogy (discussion), 1046
Ophicalcite, 212
Opik, A. A., on Dundas area, Tasmania, 374
Ordóñez, E., on geology, northern Mexico, 1008
Ordovician, Maryland, limestone aquifers, 729, 731
Ore bodies, Distribution of leachable uranium in surface samples in the vicinity of (Holland, Witter, Head, and Petti), 190
Bacu Locci sulfide deposit, Sardinia, 867, 873
fluorspar, western U. S., 667
Jacobina gold reefs, Brazil, 422
mantos, Gilman district, Colo., 690
Mt. Lyell copper deposit, Tasmania, 405, 408
pyrite, Cuba, 988, 1002
uranium, Morrison formation, Colo. Plateau (abstract), 923
zinc-lead, Shullsburg district, Wis., 149
Ore deposition, Deuteric alteration of some aplite-pegmatites of the Boulder batholith, Montana, and its possible significance to (Neuerburg), 287
Ore deposits (discussion), 1042
Africa (review), 628
albite porphyry guides (communication), 754
Argentina, structural belts and ore deposits (abstracts), 929
Canada, Proterozoic deposits (review), 112
chromite, origin, Bushveld Complex, Transvaal (abstract), 917
Colorado, San Juan Mtns. (review), 112
genesis (review), 899
source bed concept (discussions), 339, 493, 622, 623, 890
Gilman district, Colo., 690
isotope relations in uranium deposits, Colo. Plateau (abstract), 924
Lake Superior region (review), 224
leached outcrops (abstract), 921
lead-uranium, Colo. Plateau, 945
localization of ore districts (communication), 618
metallogenesis by aplite-pegmatites, 295
Miss. Valley type, origin (abstract), 915, 930
nickel-gold, 426, 435
pneumato-metasomatic deposits, 210
porphyries and ore deposits, 806
prospecting (reviews), 1055, 1056
pyrite, Minas Carlota, Cuba, 967
reserves, calculation (review), 765
Shand memorial volume (review), 113
source beds (discussion), 890
tungsten, Hong Kong, 481, 484
Turkey (review), 768
uranium, Colo. Plateau, genesis, 946
conglomerate deposits (discussions), 887, 1048
Ontario, Blind River deposit (review), 918
U.S.S.R. (reviews), 894
zinc-lead, Shullsburg district, Wis., 142

Ore deposits at Gilman, Colorado, Temperatures and depth of formation of sulfide (Lovering), 689
Ore deposits at Santa Barbara, Chihuahua, Mexico, Structure of the (Scott), 1004
Ore deposits in the Shullsburg area, Wisconsin-Illinois zinc-lead district, Factors controlling the localization of (Reynolds), 141
Ore deposits near Tajmište, Western Macedonia, Yugoslavia, Chamositic iron (Page), 1
Ore deposit of Bacu Locci (Sardinia—Italy), Lead-arsenic-sulfide (Zucchetti), 867
Ore guides, Monument Valley, Arizona and Utah, Evaluation of uranium (Evensen and Gray), 639
Ore of the Mackinaw mine, Snohomish County, Washington, Nickel-gold (Milton and Milton), 426
Ore precipitation and solubility product (communication), 617
Ore shoots, fluorite, western U. S., 671
gold, Canavieiras mine, Brazil, 422
Mt. Lyell district, Tasmania, 410
Santa Barbara district, Mexico, 1022, 1028, 1030
Ore to porphyry in the Basin and Range province U.S.A., Relationship of (Stringham), 806
Ores, Isotopic study of some Colorado Plateau (Miller and Kulp), 937
genesis (review), 900
source beds (discussions), 219, 339, 493, 622, 623
gold, mineralogy (communication), 755
iron-titanium oxides, Adirondacks, 795
manganese, India (communication), 109
Mt. Lyell district, Tasmania, 408
pyrite, Minas Carlota, Cuba, 967, 973
Santa Barbara district, Mexico, 1017, 1035
uranium, Arizona, Monument Valley, 640
South Australia, Radium Hill ores (review), 629
Ores from the Kuruman district, Cape Province, South Africa, Manganese (Frankel), 577
Origin, aplite-pegmatites, textures, 293
chromite, Transvaal, Bushveld Complex (abstract), 917
coal, 824
copper-uranium deposits, Nova Scotia, 322
fluorspar, Ill.-Ky. (abstract), 925
western U. S., 682
gold-uranium, conglomerate deposits, 424
Witwatersrand (review), 225
iron ore, Tajmište district, Yugoslavia, 13
kaolin, France, Brittany (review), 224
Origin—*Continued*
lead-zinc, Mt. Isa deposit, Queensland (discussion), 891
Mackinaw mine, Wash., 426
manganese, Kuruman district, South Africa, 593
Nairne pyritic formation, South Australia, 560
ore deposits, Miss. Valley type (abstracts), 915, 930
phosphorites, Beaufort Co., N. C., 85, 96, 99
pyrite, Minas Carlota, Cuba, 993
reverse remanent magnetization, 801
titaniferous metasediments, Cuyuna, Minn., 718
uranium, Catskill formation, Pa., 1042
leachable uranium, Monument #1 mine, Ariz., 199
Ontario, Blind River deposit (abstract), 918
zinc-lead, Shullsburg district, Wis., 143, 155
Origin of sandstone-type uranium deposits, Sulfur isotopes and the (Jensen), 598
Orogenies, Hong Kong and south China, 481
Narragansett basin, R. I., 565
Tasmania, 375, 378
Orthoclase, 45, 49
porphyry deposits, Ariz., (abstract), 931
Ostrovskii, I. A., on a binary diagram, 900
Otton, E. G., and Richardson, C. A., *Limestone aquifers of Maryland*, 722–736
Outcrops, leached outcrops (abstract), 921
Overholt, J. L., Vaux, G., and Rodda, J. L., on arizonite, 781
Oxidation, Baccu Locci ore deposit, Sardinia, 868, 875
cassiterite veins, Va., 83
coal, 829
Nairne pyritic formation, South Australia, 551
ores and rocks, Mackinaw mine, Wash., 427
uranium ores, Monument Valley, Ariz.-Utah, 658
Oxide minerals, rocks, and aero-magnetic anomalies of the Adirondack area, New York, Iron-titanium (Balsley and Buddington), 777
Oxides, 780
manganese, Ghana, Nsuta deposit (abstract), 927
Santa Barbara district, Mexico, 1017
Oxidized coals, Reflectance of (Chandra), 102

Pabst, A., on fluorescence, 300
Page, B. M., *Chamositic iron ore deposits near Tajmište, Western Macedonia, Yugoslavia*, 1–21

Palache, C., Berman, H., and Frondel, C., on hessite, 695
on pyrite, 982
on sulfides, 763
Paleostream channels, Arizona, 196, 201
Hideout No. 1 mine area, Utah, 953
Monument Valley, Ariz.-Utah, 639, 651
uranium host sites, western U. S. (abstract), 920
Paleostreams, channel deposits, 655
Palissy, B., discourses (review), 113
Paragenesis, accessory minerals in igneous rocks (discussion), 215
fluorite deposits, western U. S., 679
ores, Irish Creek area, Va., 69
Mexico, Santa Barbara district, 1035
Santa Maria del Oro deposit (abstract), 918
pyrite, Minas Carlota, Cuba, 967, 978
scheelite ore, Nev., 51
sulfides, Gilman, Colo., 705
Pa., 1041
tungsten, Hong Kong, 483
uranium, Radium Hill, South Australia (review), 629
zinc-lead, Ill.-Wis., 152
sulfides, Mackinaw mine, Wash., 436, 442
Nova Scotia, 316
Paragenetic relations, Minerals of the cassiterite-bearing veins at Irish Creek, Virginia, and their (Glass, Koschmann, and Vhay), 65
Paragonite, 554, 568, 574, 960, 962
Paramagnetic minerals, 780
Parisite, 79
Park, C. F., Jr., on ores, 693
Pascal, P., on uranium phosphates, 523
Patteisky, K., on rare gases, 835
Peach, P. A., on decrepitation, 263
Peat, composition, 825
Pecora, W. T., on pegmatites, 297
Pegmatites, genesis (review), 899
tungsten deposits, Hong Kong, 481, 483
Victory scheelite mine area, Nev., 46
Pegmatites of the Boulder batholith, Montana, and its possible significance to ore deposition, Deuteric alteration of some aplite (Neuerburg), 287
Peirce, H., on Supai formation, Ariz., 858
Pek, A. V., on replacement, 991
Pennine, 170
Pennsylvania, anthracite, x-ray study, 572
uranium, Catskill formation (abstract), 931
Pentlandite, 428, 430
Permian, Hideout No. 1 mine area, Utah, 951
Lone Pine reservoir area, Ariz., 858
Monument Valley area, Ariz., 642, 643
Perovskite, 926
Perry, V. D., on Cananea district, Mexico, 821
Perthite, porphyry deposits, Ariz. (abstract), 931
Peru, gold, Santo Domingo mine (communication), 755
Peschanski, D., and Valensi, G., on polysulfides, 495
Peters, E. D., on schist, 396
Peters, W. C., *Geologic characteristics of fluorspar deposits in the western United States*, 663–688
Peterson, N. P., *et al.*, on chloritization, 682
Petković, K. V., on geological map, Yugoslavia, 4
Petrascheck, W., on coal metamorphism, 828
Petrographic provinces, fluorspar deposits, western U. S., 682
Petroleum, chemicals industry (review), 1059
exploration, subsurface geology (review), 904
reservoir engineering (review), 357
Texas, Karnes Co. (abstract), 919
United States, future supplies (review), 626
Petrology, Boulder batholith, aplite pegmatites, Mont., 289
coal, 518
ore deposits and porphyries, 806
porphyry, Destor and Duparquet Townships, Que., 741
textbook (review), 904
Petterd, W. F., on stromeyerite, 410
Petti, R. W., with Holland, H. D., Witter, G. G., Jr., and Head, W. B., III, *Use of leachable uranium in geochemical prospecting on the Colorado Plateau*. II., 190
Pettijohn, F. J., on sulfide, 138
pH control of iron minerals, 124
Phenakite, 79, 80
Phillips, K. A., discussion by, 622
Phlogopite, 48, 960
Phosphates, apatite-like mineral (discussion), 110
oolites, mineralogy (discussion), 1046
U.S.S.R. (review), 895
Phosphoria formation, origin, 96
Phosphorites to ground water in Beaufort County, North Carolina, The relation of (Brown), 85
Phosphorus, occurrence in coal, 834
Photomicrographs—
arsenopyrite, 872
basalt and gibbsite, Hawaii, 849
biotite alteration, 166
coal, oxidized coals, 107
fluorite, 677
Nairne pyritic formation, South Australia, 550

Photomicrographs—*Continued*
ores, copper-thorium, Nova Scotia, 314
Mackinaw mine, Wash., 428
manganese, South Africa, 589
ores and rocks, Minas Carlota district, Cuba, 972
Tajmište, Yugoslavia, 12
rocks, Destor and Duparquet Townships, Quebec., 744
sulfides, Pa., 1040
tactite, 48
travertine and tuff, Calif., 33
uranium minerals, Belgian Congo, Haut Katanga (review), 767
Pierce, A. P., glow curves run by, 701
Pipes, diamondiferous, Siberia (review), 220
fluorspar deposits, western U. S., 671, 684
Lyell ore deposit, Tasmania, 408
porphyries, western U. S., 806
U.S.S.R., kimberlite, Arctic regions (review), 766
Pirson, S. J., review of book by, 357
Pirsson, L. V., on tuffs, 717
Pisani, F., on uranium carbonate, 523
Pitch, definition, 278
Pitchblende, 943, 944
Chemical environment of (Miller), 521
Pitches, 147
Place, R., review of book by, 114
Placers, diamonds, Siberia (review), 221
Plagioclase, 45, 49, 292, 977
Plans—
en echelon fold pattern, 451
Lyell ore bodies, Tasmania, 406
Mexico, San Martin mine, 1027
mineralized split, Bacu Locci, Sardinia, 871
Rhyolite Ridge, Marysvale, Utah, 208
Schundler bentonite mine, Calif., 28
Victory scheelite mine, Nev., 62
Plants, cells, replacement by pyrite, 309, 314
replacement by sulfides, Pa., 1041
hydrogen sulfide generation, 613
pitchblende precipitation by cells, 544
Plastic discs for color comparisons, 883
Plugs, Santa Barbara district, Mexico, 1012
Pneumatolysis, 347
Pneumato-metasomatic deposits, 210
Polysulfidation, 494
Porphyritization in Destor and Duparquet Townships, Abitibi West County, Quebec, Canada (Graham), 737
Porphyry in the Basin and Range province, U.S.A., Relationship of ore to (Stringham), 806
Postmasburg manganese ores, origin, South Africa, 593
Potash, geology (review), 1060
U.S.S.R. (review), 895
Pourbaix, M. J. N., on hematite, 124
Poutney, R. T., on thucolite, 490
Poyarkov, V. E., on ore deposits, 1054
Precambrian, Cuyuna range, Minnesota, 711
Destor and Duparquet Townships, Que., 739
Maryland, marble aquifers, 725
Price, T. D., and Huffman, E. H., on UO_2, 529
Prider, R. T., on albite porphyries, 754
Primary inclusions, 474
Prochlorite, 977
Prokofjew, A. P., review of book by, 765
Prospecting, beryllium, detector (abstract), 916
copper test (communication), 877
diamonds, Siberia (review), 221
geobotannical and hydrogeological methods (review), 896
manganese, Kuruman, district, South Africa, 595
ore deposits, (reviews), 1055, 1056
Lake Superior regions (review), 224
Proterozoic, Canada (review), 112
Jacobina region, Brazil, 417, 419
Protore, pyrite, 973
Prucha, J. J., on chloritization, 979
Pseudomorphs, aggregates after biotite, 165
calcite after pyroxene, 46
gibbsite after labradorite, 849, 850
goethite after hematite, 582
pyrite after magnetite (discussion), 621
pyrolusite after cryptomelane, 588, 589
Ptilolite, 31
Punched card systems with reference to geochemical problems, Design of simple (Breger), 325
Puustjärvi, V., on peat soils, 825
Pyrite, 13, 82, 124, 127, 166, 167, 173, 258, 261, 312, 313, 314, 404, 409, 414, 417, 421, 598, 601, 654, 696, 697, 705, 713, 760, 763, 873, 888, 1039
"geothermometer," 988
Pyrite deposits of Minas Carlota, Cuba, Banded (Hill), 966
Pyritic formation, a sedimentary sulfide deposit in South Australia, Geology and metamorphism of the Nairne (Skinner), 546
Pyrolusite, 582, 584, 585, 927
Pyrometasomatic deposits, Galena in (Geijer), 210
Pyrope, 220
Pyrophyllite, 960
Pyrrhotite, 82, 129, 435, 546, 550, 556, 694, 780, 874

Quartz, 43, 49, 53, 56, 74, 75, 99, 171, 173, 217, 287, 290, 407, 421, 483, 675, 717, 737, 742, 744, 867, 874, 976, 977, 980, 1017, 1034
fluid inclusions, analysis, 236, 237, 476
U.S.S.R., Aldan massif (review), 895
Quattrochiocchi, T., on pyrite, 995

Quebec, Canada, Porphyritization in Destor and Duparquet Townships, Abitibi West County (Graham), 737
peat, composition, 825
rare earths, Oka area (abstract), 926
Queensland, Mt., Isa ore deposit, origin (discussion), 891
Quinn, A. W., and Glass, H. D., *Rank of coal and metamorphic grade of rocks of the Narragansett basin of Rhode Island*, 563–576
Quinn, A. W., *et al.*, on Narragansett basin, R. I., 565
Quiring, H., on arsenopyrite, 868

Raal, F. A., x-ray measurements by, 586
Rade, J., on ore deposits, 988
Radioactivity, altered zones, Monument Valley, Ariz., 650
Catskill formation, Pa., 1038
copper-uranium ores, Nova Scotia, 317, 319
Witwatersrand beds (discussion), 757
Radiometric assays, mill products, Canavieiras mill, Brazil, 423
Radon, 945
Rahlfs, P., on sulfides, 761, 764
Ramdohr, P., discussion by, 620
discussion of discussion by, 1048
on hessite, 695
on maucherite, 429
on ulvöspinel, 780
Ramsdell, L. S., on psilomelane, 591
Ramsdell,—, on cryptomelane, 591
Rankama, K., and Sahama, T. G., on iron sulfides, 129
Ransome, F. L., on chlorite, 170
on porphyry, 820
Rare earths, occurrence in coals, 834
Quebec, Oka area (abstract), 926
Rare earths-niobium, Idaho-Mont. (abstract), 930
Rare elements, U.S.S.R. (review), 897
Rare gases, occurrence in coal, 835
Razumova, L. L., Kasatochkin, V. I., and Volarovich, M. P., on coal, 827
Reeside, J. B., Jr., on Upper Cretaceous, Colo., 702
Reflectance of oxidized coals (Chandra), 102
Reflectivity, coal, 828
sulfides (discussions), 760, 763
Reiche, P., on Lone Pine reservoir, Ariz., 857
Reinhardt, E. V., on uranium, 645
Remnant magnetization, 785, 788
Repenning, C. A., and Irwin, J. H., on Bidahochi formation, Ariz., 859
Replacement, calcite by cryptomelane, 588
fluorite replacing other minerals, 674, 677
ores, Mt., Isa Queensland (discussion), 891
Replacement—*Continued*
porphyry-sediment contacts, Que., 748
sulfides, Mackinaw mine, Wash., 429
Victory scheelite area, Nev., 49, 55
Research in coal industry, 514
Resilication, 847
Resistivity, sulfides (discussions), 760, 763
Reviews—
Admirable discourses of Bernard Palissy (La Roque), 113
Atomic age and our biological future (Brønsted), 627
Atomic energy in agriculture (Dick), 223
Bed rock geology of the East Barre area, Vermont (Murthy), Dechow, 355
Block diagrams and other graphic methods used in geology and geography. 2nd edit. (Lobeck), 502
Canadian resources, Part I. Alberta, British Columbia, Manitoba, Saskatchewan, 502
Contribution à l'Étude Géologique et Minéralogique de Quelques Gisements de Kaolin Bretons (Nicolas), 224
Diamonds of Siberia (Bobrievich, *et al.*), Alexandrov, 220
Economics of atomic energy (Goldring), 114
Einführung in die Gesteinswelt, 2nd Edit. (Schumann), 904
Elements of geology (Zumberge), 1059
Engineering geology case histories No. 2 (Trask, *et al.*), 627
Fifteen reviews of recent Russian literature on economic geology, Davidson, 894; 1056
Finding fossil man (Place), 114
Fundamental problems in study of magmatic ore deposits (Betekhtin *et al.*), Alexandrov, 899
Future supply of oil and gas (Netschert), 626
Genetic relation of mineralization to granitoid intrusions (Abdullaev), Alexandrov, 1050
Geography in the 20th Century 3rd Edit. (Taylor *et al.*), 225, 501
Geological exploration (Snelgrove *et al.*), 224
Geological principles of prospecting and exploration of ore deposits. 2nd edit. (Smirnov), Alexandrov, 1055
Geologie und Bodenschätze Afrikas (Krenkel), 628
Geologiya Sovetskoi Arktiki (Markov and Nalivkin), Davidson, 766
Getting acquainted with minerals, 2nd edit. (English and Jensen), 1059
Guide to the known minerals of Turkey. 2nd edit. (Ryan), 768
Guidebook of western San Juan Mountains, Colorado (New Mexico Geol. Soc.), Couvering, 112

Reviews—Continued
Hydrogéologie. 2nd edit. (Fourmarier), 769
Introduction to geology (Brown, Monnett, and Stovall), 629
Introduction to graphic solutions of geologic structures—Laboratory exercises and problems (MacIntosh), Broderick, 626
Landscapes of Alaska—Their geologic evolution (Williams *et al.*), 769
Landslides and engineering practice (Eckel), Legget, 897
Law of water allocation in the eastern United States (Haber and Bergen), 767
Metallic raw materials, Vol. II Zinn und Wolfram (Ahlfeld), Amstutz, 765
Mineragraphy of the Radium Hill uranium deposits and the delineation of the Whip and Geiger lodes (LaGanza), 629
Mineral Commodities of California (Jenkins and Wright), Campbell, 352
Mineral wealth of Madhya Pradesh, 356
Mineraly urana: spravochnik (Soboleva and Ludovkina), Davidson, 500
Minéraux d'uranium du Haut Katanga (Vaes and Guillemin), Fleischer, 767
Oil reservoir engineering, 2nd edit. (Pirson), 357
Old Stone Age, nature and art series (Célébonovic and Grigson), 115
Petroleum chemicals industry (Goldstein), 1059
Powder method in x-ray crystallography (Azároff and Buerger), 500
Prentice-Hall world atlas (Williams), 768
Principles of engineering geology and geotechnics (Krynine and Judd), Frink, 221
Principles of geochemistry 2nd Edit. (Mason), 502
Principles of geodynamics (Scheidegger), 628
Progress of the mineral industry of India, 1906–55, 501
Prospection électrique par courants continus (Lasfargues), 356
Proterozoic in Canada (Gill), 112
Review of Commonwealth raw materials, 767
S. James Shand, memorial volume (Taljaard *et al.*), 113
Steinsalz und Kalisalze, Part I (Lotze), 1060
Subsurface geology in petroleum exploration: A symposium (Haun and LeRoy), 904
Uranium in South Africa, 1946–1956, Bateman, 224
Reviews—Continued
Vorratsberechnung mineralischer Rohstoffe (Prokofjew, *et al.*), Amstutz, 765
Reynolds, F. M., on V, Cr, and Ni, 834
Reynolds, R. R., *Factors controlling the localization of ore deposits in the Shullsburg area, Wisconsin-Illinois zinc-lead district*, 141–163
Rhode Island, Rank of coal and metamorphic grade of rocks of the Narragansett basin of (Quinn and Glass), 563
Ricci, J. E., on "fluid phase," 346
Rich, J. L., on turbidity currents, 561
Richards, J., age determination by, 892
Richardson, C. A., with Otton, E. G., *Limestone aquifers of Maryland*, 722
Richmond, W. E., and Fleischer, M., on cryptomelane, 590
Richter, D. H., and Ingerson, E., on inclusions, 704
Riedel, —., on breccia, 673
Robertson, E. C., on limestone, 705
Robertson, F., and Vandeveer, P. L., on a paragenetic diagram, 442
Rocks, engineering properties (review), 221
Lone Pine reservoir area, Ariz., 858
magnetization, Adirondacks, 777, 796
Tajmište area, Yugoslavia, 5
uranium content of cliff faces, 195
Rocks in the Cuyuna district, central Minnesota, Titaniferous sedimentary (Schmidt), 708
Rocks of North Carolina, Chemical character of water in the igneous and metamorphic (LeGrand), 178
Rocks of the Narragansett basin of Rhode Island, Rank of coal and metamorphic grade of (Quinn and Glass), 563
Rodden, C. J., on uranium, 524
Rodis, H. G., abstract by, 926
Rods, 655
Roedder, E., *Technique for the extraction and partial chemical analysis of fluid-filled inclusions from minerals*, 235–269
on analysis of fluid inclusions, 475
on nitrogen, 263
Rolls, 655
Roman, D., on pyrite, 991
Roscoe, S. M., on sedimentary structures, 423
Rosenbusch Order of Crystallization (discussion), 215
Rosenfeld, J. L., on paragonite, 569
Rosenzweig, A., Gruner, J. W., and Gardiner, L., on uraninite, 833
Roso de Luna, I., on pyrite, 991
Ross, C. P., on fluorspar, Mont., 665
Ross, C. S., on replacement, 991
Ross, C. S., and Hendricks, S. B., on hectorite, 26

Ross, V., discussion of paper by, 759
on lead meta-autunite, 307
on resistivity and reflectivity, 763
reply to discussion by, 762
Rothrock, H. E., *et al.*, on fluorspar, New Mexico, 665
Rouir, E. V., on germanium, 832
Round, E. M., on coal flora, R. I., 565
Roy, D. M., and Roy, R., on mineral synthesis, 959
on montmorillonites, 26
Roy, D. M., Roy, R., and Osborn, E. F., on mineral synthesis, 959
Roy, R., on mica, 248
Roy, R., and Sand, L. B., on montmorillonite, 35
Roy, R., with Devries, R. C., *The influence of ionic substitution on the stability of micas and chlorites*, 958
Rubey, W. W., on iron sulfides, 129
Rubidium, occurrence in quartz, 259
Rudge, E. A., and Moon, S. E. A., on germanium, 832
Runcorn, S. K., on magnetization, 802
Runge, F., Freytag, J., and Kolbe, J., on hydrogenated lignite, 830
Russell, R. T., on fluorite, 479
Rutile, 73, 166, 167, 172, 621
Idaho, Lemhi County (abstract), 913
Ryan, C. W., review of book revised by, 768

Sabins, F. F., on plutons, 808
Sahama, T. G., on sphene, 216
Sainfeld, P., on arsenopyrite, 858
Sakai, H., on sulfur compounds, 610
Sales, R. H., on porphyry, 820
Sales, R. H., and Meyer, C., on alteration, 292
on biotite, 169
Salm-Horstmar, F., on salts, 240
Salt, Arizona, Lone Pine reservoir region, 858
geology (review), 1060
Samoyloff, V., on biotite, 173
Samples in the vicinity of ore bodies, The distribution of leachable uranium in surface (Holland, Witter, Head, and Petti), 190
Sampling, minerals for fluid inclusions, 477
ore deposits (review), 1055
uranium near ore bodies, 191
San Juan Mountains, Colorado, guidebook (review), 112
Sand, L. B., Roy, R., and Osborn, E. F., on paragonite, 959
Sand, L. B., with Ames, L. L., Jr., and Goldich, S. S., *A contribution on the Hector, California, bentonite deposit*, 22
Sandell, E. B., and Goldich, S. S., on copper, 1045
Sandell, E. B., Hey, M. H., and McConnell, D., on francolite, 110
Sands, phosphorites, N. C., 90
Sandstone, Hideout No. 1 mine area, Utah, 952
Monument Valley area, Ariz., 643
uraniferous deposits, Monument Valley, Ariz., 196
Sandstone-type uranium deposits, Sulfur isotopes and the origin of (Jensen), 598
Sanidine, 291
Santa Barbara, Chihuahua, Mexico, Structure of the ore deposits at (Scott), 1004
Santos-Ynigo, L., on pyrite, 990
Saponite, 22
(*Sardinia—Italy*), *Lead-arsenic-sulfide ore deposit of Bacu Locci* (Zucchetti), 867
Sarrot-Reynaud de Cresseneuil, J., on uranium, 833
Sasaki, A., on pyrite, 761, 763
Saskatchewan, natural resources (review), 502
Satpaeva, K. I., review of book edited by, 895
Saunders, W. M., analysis by, 570
Scanlon, W. W., on galena, 761
Scapolite, 210, 556
Schairer, J. F., and Bowen, N. L., on muscovite, 962
Schaller, W. T., on clinoptilolite, 31
Scheelite, 81
Scheelite in feldspathized granodiorite at the Victoria mine, Gabbs, Nevada (Humphrey and Wyatt), 38
Scheidegger, A. E., review of book by, 628
Schermerhorn, L. J. G., discussion by, 215
on accessory minerals, 218
Schist, Lyell area, Tasmania, 396
Schmidt, R. G., *Titaniferous sedimentary rocks in the Cuyuna district, central Minnesota*, 708–721
Schmitt, H., on Santa Barbara mining district, Mexico, 1006
on silica, 681
Schneider, H. J., on fluorite, 684
Schneiderhöhn, H., on ores, 873
on pyrite, 994
Schneiderhöhn, H., and Ramdohr, P., on ores, 873
Schnellmann, G. A., discussion by, 492
on conglomerates, 887
reply to discussion by, 887
Schofield S. J., on pyrite, 995
Scholtz, D. L., on ores, Insizwa, South Africa, 435, 436
Schopf, J. M., on aerobic decay, 826
Schopf, J. M., and Gray, R. J., on uranium, 833
Schouten, C., on pyrite, 983
Schroeder, H., on oxidation rims, 106

Schroter, G. A., and Campbell, I., on clay, 35
Schultz, C. B., on pipes, 655
Schumann, H., review of book by, 904
Schuyer, J., and van Krevelen, D. W., on molar refraction, 830
Schuyer, J., Dijkstra, H., and van Krevelen, D. W., on elasticity of coal, 830
Schwartz, G. M., *Alteration of biotite under mesothermal conditions*, 164–177
on biotite phenocrysts, 165
on gold, 986
on sericite, 401
Schwartz, W., and Muller, A., on bacteria, 826
Scientific Notes and News, 120, 232, 364, 509, 636, 775, 934
Sclar, C. B., and Smerchanski, M. G., abstract by, 926
Scorodite, 83
Scott, B., analysis by, 375
Scott, H. S., on inclusions, 263
Scott, J. B., *Structure of the ore deposits at Santa Barbara, Chihuahua, Mexico*, 1004–1037
Sea water, ionic activity, 126
Secondary inclusions, 474
Sections—
Austinville zinc mine, Va., 277
Black Brook copper-uranium deposit, Nova Scotia, 320
Canavieiras mine area, Brazil, 422
Castle and Devils Peaks, Hong Hong, 486
Deer Flat area, Utah, 955
en echelon folds, 451
fluorite deposit, Eagle Mtns., Texas, 668
Green Spring Valley, Md., 724, 726
Hector bentonite deposit, Calif., 29
Holiday Mesa area, Utah, 653
Kuruman manganese district, South Africa, 581
Lone Pine reservoir area, Ariz., 861
Lyell area, Tasmania, 390
Minas Carlota district, Cuba, 970
mineralized split, Bacu Locci, 871
North range, Cuyuna, Minn., 712
ore bodies, Minas Carlota district, Cuba, 1002
sedimentary structures, Monument #1 mine, Ariz., 197
Tajmište area, Yugoslavia, 7
zinc-lead ore bodies, Shullsburg district, Wis., 154
Sections and the third dimension, Structural (Knutson), 270
Sedimentary iron minerals, The environmental control of (Huber), 123
Sedimentary rocks (review), 1058
Bacu Locci area, Sardinia, 868
Destor and Duparquet Townships, Quebec, 739
Hideout No. 1 mine area, Utah, 951
Jacobina region, Brazil, 417, 419
Sedimentary Rocks (review)—*Continued*
Kanmantoo Group, South Australia, 546, 548, 560
Kuruman manganese district, South Africa, 580
Lone Pine reservoir area, Ariz., 858
Monument Valley area, Ariz., 196, 643, 651
Mt. Lyell district, Tasmania, 372, 383
Narragansett basin, R. I., 565, 567
Sedimentary rocks in the Cuyuna district, central Minnesota, Titaniferous (Schmidt), 708
Sedimentary sulfide deposit in South Australia, Geology and metamorphism of the Nairne pyritic formation, a (Skinner), 546
Sedimentation, diamonds and pyrope, transport, 221
fluvial deposits, western Africa (discussion), 491
Nairne pyritic formation, South Australia, 546, 548, 561
Witwatersrand beds, radioactivity (communication), 757
Sediments, auriferous conglomerates, West and South Africa (discussion), 887
chamositic ores, Yugoslavia, 13
conglomerates, uranium deposits (discussion), 1048
copper content test (communication), 877
copper-thorium, Nova Scotia, 311, 313
copper-uranium deposits, Nova Scotia, 322
Kanmantoo Group, South Australia, 546, 549, 560
Lone Pine reservoir area, Ariz., 858
phosphorites, Beaufort Co., N. C., 92
uranium deposits, Colo. Plateau and Gulf Coast (abstract), 922
uranium host rocks, western U. S. (abstract), 920
uranium in conglomerates (discussions), 489, 492, 620, 621, 757, 887, 889
Witwatersrand beds, radioactivity (discussion), 757
Seifert, H., Nickel, E., and Bruckmann, E., on pyrite, 995
Selenium, Mt. Lyell ore deposit, Tasmania, 405
Nairne pyritic formation, South Australia, 560
Selvage, 292
Sericite, 167, 169, 292, 397, 977, 980
Serpentinization, 990
Minas Carlota, Cuba, 967
Seybertite, 959, 960
Seyler, C. A., on coal, 102, 827
Seyler, C. A., and Edwards, W. J., on coal reflectivity, 828
on reflectance measurements, 102

Shales, chemical analyses, 710
Santa Barbara district, Mexico, 1009, 1030
Shaler, N. S., Woodworth, J. B., and Foerste, A. F., on coal flora, R. I., 565
Shand, S. J., memorial volume (review), 113
on pyrite, 995
on silicate melts, 345
Shapiro, L., and Brannock, W. W., on titanium, 711
Shawe, D. R., on rolls, 655
Shearing, coalification effects, 827
Victory scheelite mine area, Nev., 43
Sherman, G. D., on latosol, 846
Short, N. M., on reflectivity of minerals, 761
Shullsburg area, Wisconsin-Illinois zinc-lead district, Factors controlling the localization of ore deposits in the (Reynolds), 141
Siberia, diamonds (review), 220
Siderite, 1, 11, 12, 75, 79, 127, 407, 713
Sidgwick, N. V., on pyrrhotite, 129
Siever, R., on coal structure, 571
on x-ray study of coal, 829
Silicification, 153, 403
Alamo and Portales mine areas, N. Mex., 477, 479
fluorite deposits, western U. S., 679
Sills, porphyries, western U. S., 806
Tajmište area, Yugoslavia, 10
Silver, 874
Mexico, Santa Barbara district, 1016
Mt. Lyell mines, Tasmania, 369
Queensland, Mt. Isa deposit (discussion), 891
Simek, B. G., Coufalik, F., and Stadler, A., on germanium, 832
Simons, F. S., on arsenopyrite, 868
Simpson, D. J., on radio logs, 757
Sinkholes, limestone aquifers, Md., 724
Lone Pine reservoir area, Ariz., 862, 863
Skinner, B. J., *The geology and metamorphism of the Nairne pyritic formation, a sedimentary sulfide deposit in South Australia*, 546–562
on vacuoles, 265
Skinner, B. J., and Milton, D. J., on valeriite, 432
Skrigan, A. I., *et al.*, on wood, 826
Slickensides, Lyell ore deposit, Tasmania, 407
Smirnov, V. I., review of book by, 1055
Smith, F. G., determinations by, 989
on bibliography of inclusions, 239
on inclusions, 474
on pyrite "geothermometer," 697, 988
Smith, F. G., and Jones, R. E., discussion by, 340; reply to discussion by, 348
Smith, F. W., on Parral mining district, Mexico, 1008
Smyth, C. H., Jr., on chloritization, 979
Smythite, 130
Snelgrove, A. K., review of book edited by, 224
Snohomish County, Washington, Nickel-gold ore of the Mackinaw mine (Milton and Milton), 426
Soboleva, M. V., and Ludovkina, I. A., review of book by, 500
Society of Economic Geologists, 120, 363
Annual Meeting, St. Louis, Mo., 6–8 Nov. 1958, 911
Meeting, New York City, Feb. 17–20, 1958, 120
Sodium, occurrence in quartz, 249
Sofiano, T. A., review of book by, 1057
Soils, alumina soils, Kauai, Hawaii, 844
engineering use (review), 222
geochemistry, rare and dispersed elements (review), 896
test for copper content (communication), 877
uranium content, 191
Solids, solubility in gases (discussions), 340, 348
Solomon, M., with Wade, M. L., *Geology of the Mt. Lyell mines, Tasmania*, 367
Solubility of solids in gases (discussions), 340, 348
Solubility product and ore precipitation (communication), 617
Sorby, H. C., on inclusions, 239, 699
Sorem, R. K., and Cameron, E. N., abstract by, 927
Sosman, R. B., on quartz, 251
South Africa, Manganese ores from the Kuruman district, Cape Province (Frankel), 577
sulfides, Insizwa deposit, 436
uranium (review), 224
South Australia, Geology and metamorphism of the Nairne pyritic formation, a sedimentary sulfide deposit in (Skinner), 546
uranium, Radium Hill ores (review), 629
South West Africa, Shand memorial volume (review), 113
Spectroscopy, arsenopyrite, Va., 81
columbite, Mont., 931
fluids in inclusions, 478
igneous rocks, Cuba, 994
ores, uranium, Monument Valley, Utah, 660
phosphorites, Beaufort Co., N. C., 94
quartz, 250
Spencer, F. N., Jr., on arsenopyrite, 868
Spessartite, 556
Sphalerite, 81, 146, 407, 433, 434, 439, 546, 557, 694, 695, 705, 874, 972, 975, 1016, 1034
inclusions in sphalerite, 474
Sphene, 73, 173, 216, 977

Spicer, H. C., on geothermal gradients, 703
Spiroff, K., on magnetite, 138
Sprigg, R. C., and Campana, B., on Kanmantoo Group, South Australia, 546
Sprigg, R. C., and Wilson, R. B., on Kanmantoo Group, South Australia, 546
Sprigg, R. C., Whittle, A. W. G., and Campana, B., on Kanmantoo Group, South Australia, 546
Springs, analyses, North Carolina, 182
limestone aquifers, Md., 722, 727, 735
Spurr, J. E., on metasomatism, 997
on Monte Cristo district, Wash., 427
on silicification, 680
on solutions, 143
Sreenivas, B. L., communication by, 109
Staatz, M. H., and Osterwald, F. W., on fluorite pipe, Utah, 672
Stadnichenko, T., Murata, K. J., and Axelrod, J. M., on ash of *Cupressinoxylon wardi*, 832
Stadnichenko, T., Zubovic, P., and Hufschmidt, E. L., on germanium, 832
Stadnichenko, T., Zubovic, P., and Sheffey, N. B., on beryllium, 835
Statistical analysis of coal composition, 828
Stauffer, C. R., on conodonts, 110
Stearns, H. S., on Koloa volcanics, 842
Stegmüller, L., on fluorite, 679
Steiger, G., spectroscopic test by, 78
Stephens, J. D., and Sand, L. B., abstract by, 932
Stephenson, E. L., on plutons, 808
Stern, T. W., *et al.*, on fluorescence, 300
Steven, T. A., on fluorspar, Colo., 665
Stevens, R. E., analysis by, 78
Stibnite, 487
crystal structure, 764
Stickney, A. W., on replacement, 991
Stieff, L. R., and Stern, T. W., on lead, 938
Stieff, L. R., Stern, T. W., and Milkey, R. G., on lead, 938
on uranium, 645
Stieff, L. R., Stern, T. W., and Sherwood, A. M., on fluorescence, 300
Stokes, W. L., and Phoenix, D. A., on anticlines, 954
Stone Age, nature and art (review), 115
Stose, G. W., on Parral mining district, Mexico, 1008
Strakhov, N. M., *et al.*, review of book by, 1058
Stratigraphy, Bacu Locci area, Sardinia, 868
Beaufort, Co., N. C., 88
Carboniferous, Nova Scotia, 312
Catskill formation, Pa., 1041
Frederick and Hagerstown valleys, Md., 729, 731
Kuruman manganese district, South Africa, 579
Stratigraphy—*Continued*
Lone Pine reservoir area, Ariz., 854, 858
Monument Valley, Ariz.-Utah, 196, 642
Shullsburg area, Wis., 144
Tajmište area, Yugoslavia, 6
Tasmania, Mt. Lyell district, 372, 383
titaniferous sedimentary rocks, Cuyuna, Minn., 708, 711
Utah, Hideout No. 1 mine, Blanding, 949, 951
Street, N., communication by, 617
Stringham, B., *Relationship of ore to porphyry in the Basin and Range province, U.S.A.*, 806–822
on siderite, 407
Stringham, B., and Adair, B. H., on Kinsley stock, Nev., 807
Stromeyerite, 763
Structural relations at the Hideout No. 1 uranium mine, Deer Flat area, San Juan County, Utah (Finnell and Gazdik), 949
Structural sections and the third dimension (Knutson), 270
Structure, Austinville zinc mine, Va., 277
folds, Shullsburg district, Ill.-Wis., 142, 148, 149, 155
geodynamics (review), 628
graphic methods (review), 357
graphic solutions (review), 626
ground-water characteristics of structures, N. C., 185
Hector area, California, 25
Hideout No. 1 mine area, Utah, 952
lineaments and ore districts (communication), 618
Lone Pine reservoir area, Ariz., 862
Monument Valley, Ariz., 642
Mt. Lyell district, Tasmania, 380, 390
ore deposits (review), 903
Santa Barbara district, Mexico, 1012, 1020
Tajmište district, Yugoslavia, 1, 15
U.S.S.R., Krivoi Rog iron basin (review), 894
Vermont, East Barre area (review), 355
Victory scheelite mine area, Nev., 40, 44
wrinkles, 16
Structure of the ore deposits at Santa Barbara, Chihuahua, Mexico (Scott), 1004
Structures and ore deposits (discussion), 892
Substitution on the stability of micas and chlorites, Influence of ionic (Devries and Roy), 958
Subtitanhematite, 801
Suggate, R. P., on coal, 831
Sulfates, 551

Sulfide deposit in South Australia, Geology and metamorphism of the Nairne pyritic formation, a sedimentary (Skinner), 546
Sulfide ore deposit of Bacu Locci (Sardinia—Italy), Lead-arsenic (Zucchetti), 867
Sulfide ore deposits at Gilman, Colorado, Temperatures and depth of formation of (Lovering), 689
Sulfides, 173, 490, 1039
copper-uranium, Nova Scotia, 312
geochemistry and mineralogy (discussions), 759, 762
Irish Creek, Va., 76
Mackinaw mine, Wash., 426, 427
Mexico, Santa Barbara district, 1016
Mt. Lyell copper deposit, Tasmania, 404
Nairne pyritic formation, South Australia, 546, 556
New Brunswick, Bathurst district, genesis (discussion), 624
Pennsylvania, Catskill formation (abstract), 932
solubility in solutions (discussion), 494
Tri-State district, inclusions (abstract), 929
Sulfur, occurrence in coal, 833
pyrite, Lyell area, Tasmania, 414
Sulfur isotopes and the origin of sandstone-type uranium deposits (Jensen), 598
Sullivan, C. J., discussion of paper by, 1042
on lead-zinc provinces, 493
on ore genesis, 1053
Sunagawa, I., on pyrite, 983
Sundius, N., and Byström,—., on muscovites, 963
Supergene copper-uranium deposits in northern Nova Scotia (Brummer), 309
Sverdrup, H. U., Johnson, M. W., and Fleming, R. H., on sea water, 126
on upwelling waters, 96
Swain, F. M., on Castle Hayne limestone, 88
Sweden, galena in pyrometasomatic deposits, 210
Synthesis, montmorillonites and saponite, 26
pitchblende, 522, 527, 542
Systems, Cu-Fe-S system, 441
Szabo, A., *et al.*, on partition function ratios, 610
Szádeczky-Kardoss, E., on coal metamorphism, 827
Szalay, S., on uraniferous coals, 833

Tables, analyses, ash and soil, Tenn., 916
basalt and gibbsite, Hawaii, 852
bentonite, etc., Calif., 31
beryl, Va., 78
coal, R. I., 570
fluid inclusions in chert and quartz, 476
Tables—*Continued*
ground water, North Carolina, 180
ores, wolframite, Hong Kong, 485
phosphate oolites, 1047
phosphorites, N. C., 95
rocks, Cuyuna district, Minn., 710
Mt. Lyell district, Tasmania, 375
Victory scheelite mine area, Nev., 52
sulfides, Nova Scotia, 317
uranium minerals, Colo. Plateau, 939
chemical composition, coals, 103
chlorites and micas, substitutions, 959
Cu-Zn minerals, thermodynamic properties (abstract), 915
entries in triangular coding, 329
fluorspar, textural types, 673
free energies, iron compounds, 126
minerals, Monument #1 mine, Ariz., 198
minerals and intensity of oxidation, Adirondacks, 783
ore deposits, Basin and Range Province, U. S., 810
paragenesis, scheelite ore, Nev., 51
paragenesis and minerals, Irish Creek, Va., 66, 71
pyrite and pyrrhotite composition and unit cell data, 556
reflectance of coals, 103
research expenditures on coal, 515
spectroscopy, quartz, 250
sphalerite, Fe-Zn content, Colo., 697
stratigraphy, Kuruman manganese district, South Africa, 580
Lone Pine reservoir area, Ariz., 859
Monument Valley area, Ariz., 643
Mt. Lyell district, Tasmania, 372, 383
Nova Scotia, northern Nova Scotia, 312
Shullsburg area, Wis., 144
Tajmište area, Yugoslavia, 6
sulfur isotopes in uranium deposits, 601
uranium compounds, 529
uranium-gold reefs, sedimentary features, 424
vein groups, Santa Barbara district, Mexico, 1019
x-ray diffraction data, pyrrhotite, 557
zeolite, 32
Tables for uranium and thorium minerals, Identification (Volborth), 300
Tactite, 46, 47
Tajmište, Western Macedonia, Yugoslavia, Chamositic iron ore deposits near (Page), 1
Talc, 960
Taljaard, M. S., *et. al.*, review of book edited by, 113
Tamura, T., Jackson, M. L., and Sherman, G. D., on gibbsite, 844
Tarr, W. A., and Neuman, L. M., on vacuoles, 265
Tasmania, Geology of the Mt. Lyell mines (Wade and Solomon), 367

Taylor, G., *et al.*, reviews of books by, 225, 501
Teall, J. J. L., on orthoclase, 487
Teas, L. P., on sphalerite, 990
Technique, analyses, fluid inclusions in minerals, 236, 240, 473
uranium, 523
block diagrams and graphic methods (review), 502
coal studies, 823, 827, 828, 829
detector for Be prospecting (abstract), 916
geochemistry of coal, 827, 829
geothermometry methods, 693
graphic methods in structural geology (review), 357
graphic solutions of structures (review), 626
identification of uranium and thorium minerals, 301
oxidation of coal, 102
powder method in x-ray crystallography (review), 500
prospecting geobotanical and hydrogeological methods (review), 896
punched cards, 325
sampling for x-ray study, hectorite, 27
sampling uranium near ore bodies, 191
sealing a leaking reservoir, 864
separation of sulfides from uranium minerals, 599
solution for angle of departure, 273
stability tests, chlorite and mica, 958
study of sedimentary rocks (review), 1058
tests for copper in soils, 877
ZnS solubility in water (abstract), 914
Technique for the extraction and partial chemical analysis of fluid-filled inclusions from minerals (Roedder), 235
Tegengren, F. R., *et al.*, on Kallmora silver mine, Sweden, 211
Teichmüller, R., and Teichmüller, M., on coal, 827
Temperatures and depth of formation of sulfide ore deposits at Gilman, Colorado (Lovering), 689
Tennessee, manganese, geochemical prospecting (abstract), 916
zinc, Jefferson City mine (abstract), 921
Tetrahedrite, 694, 705
Texas, fluorspar, Eagle Mtns., 667
ore deposits and porphyries, 812
quartz, analysis of inclusions, 258
uranium, Gulf Coast (abstract), 922
Karnes Co. (abstracts), 919, 922, 928
Textbooks, geochemistry (review), 502
geology (reviews), 629, 1059
geology and mineralogy (review), 904
graphic methods in structural geology (review), 357
graphic solutions to structures (review), 626
Textbooks—*Continued*
hydrogeology (review), 769
mineralogy (reviews), 1057, 1059
Prentice-Hall world atlas (review), 768
Textures, cockade structure, 1032, 1033
definition, 809
fluorite deposits, western U. S., 672
Nairne pyritic formation, South Australia, 552
ores, "wood-cell" structure, 588, 589
sulfides, Gilman district, Colo., 694
Theander, O., on sphagnum peat, 825
Thermal analysis, cryptomelane, South Africa, 592
Thermoluminescence, 701
Thiadens, A. A., on limestones and schists, 971
Thiel, G. A., on alumina, 850
Thiele, H., and Kettner, H., on cellulose, 824
Thiessen, R., on coal, 824
Thode, H. G., Kleerskoper, H., and McElcheran, D., on S^{33}, 609
Thode, H. G., Macnamara, J., and Collins, C. B., on hydrogen sulfide, 604
on pyrite, 699
Thode, H. G., Macnamara, J., and Fleming, W. H., on S^{33}/S^{34} ratios, 605
Thode, H. G., Wanless, R. K., and Wallouch, R., on S^{33}, 609
Thompson, J. B., on water pressure, 555
Thompson, M. E., Ingram, B., and Gross, E. B., on fluorescence, 300
Thompson, M. E., Weeks, A. D., and Sherwood, A. M., on rabbittite, 300
Thorium minerals, Identification tables for uranium and (Volborth), 300
Thorium: Uranium Ratio (discussions), 489, 622, 890
Thucolite, 620, 888
Thureau, G., on Mt., Lyell district, Tasmania, 369
Thurston, W. R., *et al.*, on fluorspar, Utah, 665
Tillite, Mt. Lyell district, Tasmania, 379
Tin (review), 765
Titaniferous magnetite, 780
Titaniferous sedimentary rocks in the Cuyuna district, central Minnesota (Schmidt), 708
Titanium oxide minerals, rocks and aeromagnetic anomalies of the Adirondack area, New York, Iron (Balsley and Buddington), 777
Toenges, A. L., *et al.*, on coal, R. I., 567
Tokuda, S., on *en echelon* folding, 448
Tomkeieff, S. I., on coal geochemistry, 824
Tonetti, L., determination by, 590
Tourmaline, 54, 56, 79, 168, 169, 173, 287, 291, 293, 714
Trace elements, quartz, trace-element content, 249

Transvaal, chromite, Bushveld Complex, origin (abstract), 917
Shand memorial volume (review), 113
Witwatersrand, bankets, gold-uranium deposits, 423
origin (discussions), 758, 887
uranium deposits (discussion), 620
Trask, P. D., review of book edited by, 627
Triassic, Hideout No. 1 mine area, Utah, 951
Lone Pine reservoir area, Ariz., 859
Monument Valley area, Ariz., 643
Tajmište area, Yugoslavia, 8
Trifinow, I., and Phillipow, A., on coal, 827
Trifinow, I., and Toschew, G., on pressure on coal, 827
Tri-State district, inclusions in sulfides (abstract), 929
Trofimov, A. V., on C^{13}/C^{12} ratios, 830
Troilite, isotopic sulfur content, 598
Trotter, F. M., on coalification, 827
Tucker, W. B., and Sampson, R. J., on bentonite, 23
Tudge, A. P., and Thode, W. G., on sulfate, 610
Tuffs, Cuyuna range, Minn., 717
Tungsten (review), 765
occurrence with porphyries, 815
Tungsten mineralization in Hong Kong and the New Territories (Davis), 481
Tunnels, Colorado, Mancos shale (review), 627
Pawtucket, R. I., 567
Turkey, mineral resources (review), 768
Turner, F. J., on joints, 956
Tuttle, O. F., on quartz, 262
Twelvetrees, W. H., on schist, 396
Tweto, O., abstract by, 928
on Paleozoic, Pando area, Colo., 702
Tweto, O., and Lovering, T. S., on Gilman district, Colo., 690
Tyler, S. A., on titania, 710
Tyler, S. A., and Twenhofel, W. H., on carbon dioxide, 132
Tyler, S. A., Barghoorn, E. S., and Barrett, L. P., on Gunflint formation, 350
Tyrrell, G. W., on aplite, 293

Uglow, W. L., on pyrite, 992
Ulexite, 925
Ulke, T., on cassiterite, 66
Ulvöspinel, 780
Umbgrove, J. H. F., on ore deposits, 988
Umova, M. A., Glebov, R. I., and Shibanov, P. N., on inclusions, 240
Umpleby, J., on Mackay district, Idaho, 821
Unakite, 74
Underground water, hydrogeology (review), 769
India, Neyveli lignite area (abstract), 920
Underground water—*Continued*
Lone Pine reservoir area, Ariz., 854
Maryland limestone aquifers, 722
Minnesota, Lyon Co. (abstract), 926
Wyoming, Gas Hills area (abstract), 923
United Kingdom, atomic energy (review), 114
coal, reflectance of oxidized coals, 102
Commonwealth raw materials (review), 767
United States, Geologic characteristics of fluorspar deposits in the western (Peters), 663
Relationship of ore to porphyry in the Basin and Range province (Stringham), 806
coal industry, 512
oil and gas, future supplies (review), 626
water, allocation law in eastern U. S. (review), 767
Unmixing, sulfides, Mackinaw mine, Wash., 426, 436
Uraninite, 225, 417, 888, 919
Uranium, Belgian Congo, Haut Katanga, minerals (review), 767
Colo. Plateau, composition and size of deposits (abstract), 923
isotopic data, 937
conglomerate deposits (discussions), 489, 492, 620, 621, 887, 1048
host rocks, western U. S. (abstract), 920
Lyell ore deposit, Tasmania, 409
mineralogy, U.S.S.R. (review), 500
New Mexico, Grants district (abstracts), 669, 919, 932
Laguna district, genesis (abstract), 924
Nova Scotia, copper-uranium deposits (discussion), 1038
occurrence in coal, 833
Ontario, Blind River deposit (abstract), 918
Pennsylvania, Catskill formation (abstract), 931
pitchblende, chemistry, 521
South Africa (review), 224
South Australia, Radium Hill ores (review), 629
Texas, Karnes Co. (abstracts), 919, 922, 928
Utah, Marysvale deposit, 686
Wyoming, Gas Hills area (abstract), 923
Uranium and thorium minerals, Identification tables for (Volborth), 300
Uranium deposits, Sulfur isotopes and the origin of sandstone-type (Jensen), 598
Uranium deposits in northern Nova Scotia, Supergene copper (Brummer), 309
Uranium in surface samples in the vicinity of ore bodies, The distribution of leachable (Holland, Witter, Head, and Petti), 190

Uranium mine, Deer Flat area, San Juan County, Utah, Structural relations at the Hideout No. 1 (Finnell and Gazdik), 949
Uranium ore guides, Monument Valley, Arizona and Utah, Evaluation of (Evensen and Gray), 639
Uranium-bearing auriferous reefs at Jacobina, Brazil (Bateman), 417
Uranium-lead age determination method, 942
U.S.S.R., Arctic regions, geology (review), 766
diamonds, Siberia (review), 220
economic geology books (reviews), 894, 1056
history of ore deposit study (review), 899
Ussar, M., on fossil resin, 831
Utah, Evaluation of uranium ore guides, Monument Valley, Arizona and (Evensen and Gray), 639
Structural relations at the Hideout No. 1 uranium mine, Deer Flat area, San Juan County (Finnell and Gazdik), 949
alteration, U. S. mine (abstract), 932
fluorite, Thomas Range, 671
lead minerals, isotopic data, 940
ore deposits and porphyries, 810
quartz, analysis of inclusions, 258
uranium, sulfur isotope ratios, 601, 607
uranium near ore bodies, 190, 207
Uyeda, S., on magnetization, 802

Vaes, J. F., and Guillemin, C., review of book by, 767
Vaes, J. F., and Kerr, P. F., on fluorescence, 300
Valleriite, 432, 438
Vanadium, geochemistry, Monument Valley, Ariz.,-Utah, 658
Monument Valley area, Ariz., 197
occurrence in coal, 834
Van Alstine, R. E., on fluorspar, Colo., 665
Van Couvering, M., review by, 112
Van der Waals,—., and Kohnstamm,—., on binary systems, 349
Vanderwilt, J. W., and King, R. U., on Climax district, Colo., 821
van Krevelen, D. W., on coal 827
on vitrinite, 106
van Krevelen, D. W., and Chermin, H. A. G., on coal, 828
van Krevelen, D. W., and Schuyer, J., on coal geochemistry, 824
Van Vloten, R., on phosphorites, 96
van Vucht, H. A., Rietveld, B. J., and van Krevelen, D. W., on coal, 829
Varier, N. S., on fossil resin, 831
Varnes, D. J., on graphic locator, 950
Varossieau, W. W., on wood, 824
Varossieau, W. W., and Breger, I. A., on cellulose, 824
Veins, fluorite, New Mexico, 671
Nairne pyritic formation, South Australia, 551, 552
ore formation (review), 901
quartz, Victory scheelite mine, Nev., 53
Santa Barbara district, Mexico, 1013, 1018, 1030
tungsten, China and Hong Kong, 481, 483
uraninite, Marysvale, Utah, 208
Veins at Irish Creek, Virginia, and their paragenetic relations, Minerals of the cassiterite-bearing (Glass, Koschmann, and Vhay), 65
Venter, J., and Coppens, L., on mineral matter in coal, 831
Verhoogen, J., on quartz, 251
on solubility product, 617
Vermiculite, 83
Vermont, copper, field determinations, 885
East Barre area (review), 355
Vhay, J. S., with Glass, J. J., and Koschmann, A. H., *Minerals of the cassiterite-bearing veins at Irish Creek, Virginia, and their paragenetic relations*, 65
Victoria, gold, Stawell field, folds, 472
Victory mine, Gabbs, Nevada, Scheelite in feldspathized granodiorite at the (Humphrey and Wyatt), 38
Viktorov, S. V., review of book by, 896
Vinogradov, A. P., review of book by, 896
Vinogradov, A. P., *et al.*, on sedimentary sulfides, 604
Violarite (?), 432
Virginia, and their paragenetic relations, Minerals of the cassiterite-bearing veins at Irish Creek (Glass, Koschman, and Vhay), 65
zinc, Austinville mine, section, 277
Vitrinite, 102
Vlisidis, A., partial analyses by, 783
Voge[1],—., on ore reserve classifications, 766
Vogelsang, H., on inclusions, 238
Vogt, J. H. L., on orthoclase, 487
Vogt, T., on pyrite, 992
Volborth, A., *Identification tables for uranium and thorium minerals*, 300–308
on minerals, 300
Volcanoes, Kauai Island, Hawaii, 844
Volchok, H. L., and Kulp, J. L., on radon leakage, 946
Vol'fson, F. G., on structures of ore deposits (review), 903
von Strese, H., and Hofmann, U., on bentonite, 25
Vugs, 146, 1034
Vul'chin, E. I., on fluid inclusions, 260

Wade, M. L., and Solomon, M., *Geology of the Mt. Lyell mines, Tasmania*, 367–416

Wager, L. R., and Mitchell, R. L., on trace element distribution, 216
Wahler, W., on inclusions, 474
on solutions, 240
Waitz, P., on Parral mining district, Mexico, 1008
Walker, E. H., on limestone, 725
Walker, G. W., and Osterwald, F. W., on Marysvale area, Utah, 207
Walker, W. J., discussion by, 219
Walpole, B. P., discussion by, 890
Warburg, E., and Tegetmeier, F., on quartz, 251
Ward, H. J., communications by, 618, 754
Washington, H. S., on basalt, 710
Washington, Nickel-gold ore of the Mackinaw mine, Snohomish County (Milton and Milton), 426
Wasserstein, B., on fluorine, 667
Water, hydrogeology (review), 769
inclusions in sulfides, Tri-State district (abstract), 929
United States, allocation law, eastern U. S. (review), 767
Water in the igneous and metamorphic rocks of North Carolina, Chemical character of (LeGrand), 178
Waters, A. C., and Granger, H. C., on uraniferous solutions, 612
Watson, T. L., on epidote, 74
on Irish Creek area, Va., 69
Waxes, extraction from coal, 830
Weathering (review), 1058
basalt flows, Hawaii, 842, 844, 848
basaltic volcanics, Cuyuna, Minn., 720
iron formations (discussion), 349
Wedges, Mexico, Santa Barbara district, 1025
Weed, W. H., on alteration, 292
on Sierra Madre Occidental, Mexico, 1008
Weeks, A. D., and Truesdell, A. H., abstract by, 932
Weeks, A. D., Levin, B., and Bowen, R. J., abstract by, 928
Weeks, L. G., on concretions, 1010
Weis, P. L., on solutions, 239
Weiser, H. B., on magnetite, 137
Welker, H., and Weiss, H., on band structure, 762
Wells, limestone aquifers, Md., 722, 726
Wentworth, C. K., on Kauai island, Hawaii, 844
on tuff, 710
Werner, S., on magnetite, 788
Western Australia, Coolgardie ore deposits (communication), 755
folds, 453
White, C. H., on ore fluid, 997
White, D. A., on magnetite, 137
White, D. E., abstract by, 929
White, M. G., on Jacobina reefs, Brazil, 417
Whiting, F. B., abstract by, 929
Wichers, E., Finn, A. N., and Clabaugh, W. S., on glass, 255
Wickman, F. E., on coal, 830
Wiebols, J. H., discussion by, 757
Wiese, R. G., Jr., on sulfides, 323
Wilder, C. D., on uranyl carbonate, 523
Williams, D., on sulfides, 979
Williams, H., on intrusives, 644
Williams H., *et al.*, review of book edited by, 769
Williams, J. E., review of book edited by, 768
Williams,—., on accessory minerals, 217
Willman, H. B., on pitch-flat structures, 143
Willman, H. B., and Reynolds, R. R., on pitch-flat structures, 143
Wilson, I. F., and Rocha, V. S., on Talamantes district, Mexico, 1008
Wilson, J. T., on sialic areas, 683
Wilson, J. T., Russel, R. D., and Farquhar, R. M., on lead ores, 624
Wilson, M. E., on fluorite breccia, 678
Winchell, A. N., on sericite, 167
Wisconsin-Illinois zinc-lead district, Factors controlling the localization of ore deposits in the Shullsburg area (Reynolds), 141
Witkind, I. J., on stratigraphy, Monument Valley area, Ariz., 643
Witkind, I. J., Thaden, R. E., and Lough, C. F., on Monument Valley area, Ariz., 196
Witter, G. G., Jr., with Holland, H. D., Head, W. B., III, and Petti, R. W., *Use of leachable uranium in geochemical prospecting on the Colorado Plateau.* II., 190
Wöhler, F. von, UO_2, 522
Wolframite, 78, 483
Wollastonite, 693
Wood, decomposition, 824
Shinarump conglomerate, 651, 653
"Wood cell structure," cryptomelane-calcite, 588, 589
World, Prentice-Hall atlas (review), 768
Wright, H. D., and Shulhof, W. P., on sericite, 167
Wright, L. A., *et al.*, on bentonite, 24
Wright, R. J., on lead isotopes, 944
Wyatt, M., with Humphrey, F. L., *Scheelite in feldspathized grandiorite at the Victory mine, Gabbs, Nevada*, 38
Wynne-Jones, W. F. K., Blayden, H. E., and Shaw, F., on pyridine extracts, 830
Wyoming, uranium, Gas Hills area (abstract), 923
sulfur isotope ratios, 603, 606

X-ray crystallography, powder method (review), 500

X-ray study, anthracite, R. I., 571
chlorites and micas, 959
coal, 827
hausmannite-cryptomelane, 586
heulandite, mordanite, and zeolite, 32
muscovite, South Australia, 554
uranium precipitates, 526

Yakubova, V. V., on fluid inclusions, 260
Yoder, H. S., and Eugster, H. P., on Mg-phlogopite, 959
on muscovite, 554
Yoder, H. S., Stewart, D. B., and Smith, J. R., on alkali feldspars, 555
Yohe, G. R., *et al.*, on coal oxidation, 829
Yugoslavia, Chamositic iron ore deposits near Tajmište, Western Macedonia (Page), 1
coal, sulfur content, 834

Zakharchenko, A. I., on calcium, 248
Zavaritskii, A. N., on pegmatites (review), 899
review of book by, 1057
Zavaritsky, A. N., *et al.*, on replacement, 991
Zavaritsky, V. A., on pyrite, 992
Zeller, E. J., on thermoluminescence glow peaks, 703
Zeolite, 30
Zig-zag *en echelon* fold pattern, 450
Zinc, Colorado, Gilman district, 689
Mt. Lyell district, Tasmania, 413
New Brunswick, Bathurst district (discussion), 623
Queensland, Mt. Isa deposit (discussion), 891
Zinc—*Continued*
Tennessee, Jefferson City mine (abstract), 921
Utah, U. S. mine, alteration (abstract), 932
Virginia, Austinville zinc mine, structure, 277
Zinc-lead district, Factors controlling the localization of ore deposits in the Shullsburg area, Wisconsin-Illinois (Reynolds), 141
Zircon, 73, 216
Zirkel, F., on inclusions, 238
Zobell, C. E., on bacteria, 614
Zobell, C. E., and Anderson, D. Q., on bacteria, 613
Zobell, C. E., and Rittenberg, S. C., on sulfide, 139
Zobell, C. E., Grant, C. W., and Haas, H. F., on bacteria, 614
Zoisite, 83, 170
Zoning (review), 1053
fluorite deposits, western U. S., 679
lead-zinc, Ill.-Wis., 152
Lyell area, Tasmania, 402
Mexico, Santa Barbara district, 1017
Missouri, southeast Mo. (abstract), 917
Monument Valley, Ariz.-Utah, 659
Shullsburg zinc-lead district, Wis., 154
Zucchetti, S. C., *The lead-arsenic-sulfide ore deposit of Bacu Locci (Sardinia—Italy)*, 867–876
Zumberge, J. H., review of book by, 1059
Zwietering, P., Overeem, J., and van Krevelen, D. W., on diffusion of gases in coal, 830

ADVERTISEMENTS

Patrons of this journal are requested to refer to ECONOMIC GEOLOGY AND THE BULLETIN OF THE SOCIETY OF ECONOMIC GEOLOGISTS when consulting advertisers.

THE GLACIAL MAP OF CANADA

Scale 1″ = 60 miles

published by the Geological Association of Canada with support from the Geological Survey of Canada, Defence Research Board and the National Research Council

Price $2.00

The Geological Association of Canada

P.O. Box 4029, Terminal "A" **Toronto, Ontario**

FIFTIETH ANNIVERSARY VOLUME

ECONOMIC GEOLOGY

1905–1955

CONTENTS

Part I

FOREWORD ii
ECONOMIC GEOLOGY ..... *Alan M. Bateman* 1
METALLOGENETIC PROVINCES AND EPOCHS ..... *F. S. Turneaure* 38
THERMAL SPRINGS AND EPITHERMAL ORE DEPOSITS ..... *Donald E. White* 99
THE CLASSIFICATION OF ORE DEPOSITS ..... *James A. Noble* 155
STRUCTURE OF HYDROTHERMAL ORE DEPOSITS ..... *H. E. McKinstry* 170
THE ZONAL THEORY OF ORE DEPOSITS ..... *Charles F. Park, Jr.* 226
TEMPERATURES IN AND NEAR INTRUSIONS ..... *T. S. Lovering* 249
SYNTHETIC MINERALS ..... *W. A. Weyl* 282
HYDROTHERMAL ALTERATION AS A GUIDE TO ORE ..... *George M. Schwartz* 300
OXIDATION OF COPPER SULFIDES AND SECONDARY SULFIDE ENRICHMENT ..... *Charles A. Anderson* 324
METHODS AND PROBLEMS OF GEOLOGIC THERMOMETRY ..... *Earl Ingerson* 341
SEDIMENTARY DEPOSITS OF RARE METALS ..... *Konrad B. Krauskopf* 411
ORIGIN OF URANIUM DEPOSITS ..... *V. E. McKelvey, D. L. Everhart and R. M. Garrels* 464

Part II

ENGINEERING GEOLOGY—A FIFTY YEAR REVIEW ..... *Robert F. Legget* 534
INFLUENCE OF GEOLOGICAL FACTORS ON THE ENGINEERING PROPERTIES OF SEDIMENTS ..... *Karl Terzaghi* 557
RECENT DEVELOPMENTS IN CLAY MINERALOGY AND TECHNOLOGY ..... *Ralph E. Grim* 619
PROPERTIES OF CALCIUM AND MAGNESIUM CARBONATES AND THEIR BEARING ON SOME USES OF CARBONATE ROCKS ..... *D. L. Graf and J. E. Lamar* 639
THE QUANTITATIVE APPROACH TO GROUND-WATER INVESTIGATIONS ..... *John G. Ferris and A. Nelson Sayre* 714
TIME OF PETROLEUM ACCUMULATION ..... *A. I. Levorsen* 748
COAL PETROLOGY ..... *C. E. Marshall* 757
THE USE OF GAMMA RAY MEASUREMENTS IN PROSPECTING ..... *William L. Russell* 835
ECONOMIC APPLICATIONS OF PALEOCOLOGY ..... *Samuel P. Ellison* 867
GEOPHYSICS APPLIED TO PROSPECTING FOR ORES ..... *Louis B. Slichter* 885
MINOR ELEMENTS IN SOME SULFIDE MINERALS ..... *Michael Fleischer* 970
THE STUDY OF PEGMATITE DEPOSITS ..... *Richard H. Jahns* 1025–1130

See order blank in fore-part of this issue.

ECONOMIC GEOLOGY PUBLISHING COMPANY

105 Natural Resources Building, Urbana, Illinois

Price to Subscribers (including members, non-member Journal subscribers, and students whether subscribers or not) $6.00

Price to Non-Subscribers to Journal 8.00

Leitz

SATISFIES THE MOST EXACTING REQUIREMENTS

RESEARCH POLARIZING MICROSCOPE

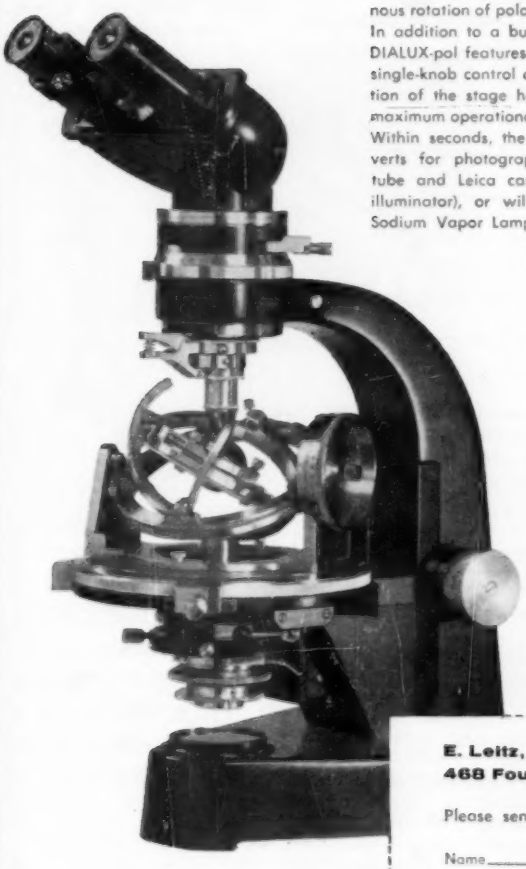
DIALUX-POL

The new *LEITZ* DIALUX-pol is the most advanced, universal polarizing research microscope ever manufactured. It was designed for the geologist, mineralogist, petrographer, paleontologist, and the industrial research microscopist.

The DIALUX-pol maintains the principle of interchangeability, famous with all *LEITZ* precision instruments, so that it is readily used for transmitted light as well as for reflected-polarized light. With the simple addition of a connecting bar, it provides synchronous rotation of polarizer and analyzer.

In addition to a built-in light source and condenser system, the DIALUX-pol features many other operational advantages: unique single-knob control of both coarse and fine adjustment by alteration of the stage height (and not the tube), thus focusing with maximum operational ease.

Within seconds, the DIALUX-pol, through *LEITZ* accessories, converts for photography (through combined monocular-binocular tube and Leica camera), for ore microscopy (through vertical illuminator), or will accommodate the *LEITZ* Universal Stage, Sodium Vapor Lamp, and other facilities.



- monocular or binocular vision
- combination tube FS for photography
- synchronous polarizer-analyzer rotation upon request
- dual coarse and fine focusing
- built-in light source; 6-volt, 2.5-amp, variable intensity
- vertical illumination for ore microscopy
- polarizing filters or calcite prisms
- adaptable to all universal stage methods

Send for the DIALUX-pol information bulletin—then see and examine this fine instrument for yourself.

E. Leitz, Inc., Department G-12
468 Fourth Ave., New York 16, N. Y.

Please send me the *LEITZ* DIALUX-pol brochure.

Name_____

Street_____

City_____ Zone_____ State_____

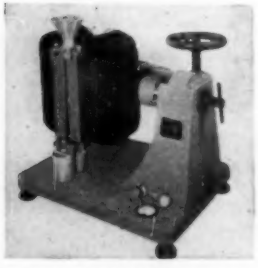
E. LEITZ, INC., 468 FOURTH AVENUE, NEW YORK 16, N. Y. 35150

Distributors of the world-famous products of Ernst Leitz G. m. b. H., Wetzlar, Germany—Ernst Leitz Canada Ltd.

LEICA CAMERAS · LENSES · MICROSCOPES · BINOCULARS

The variety of separations made possible by the ISODYNAMIC Magnetic Separator is practically infinite. Its use is limited only by the great number of magnetic minerals in nature—even many not usually thought of as magnetic—and their range of susceptibilities.

INCLINED FEED



Vertical Feed

Peculiar to the ISODYNAMIC Separator is the special configuration of the pole pieces which accounts for its exceptional selectivity. This results in a constant force on a particle of given susceptibility, regardless of its position in the operating space.

For more complete information, write for Bulletin 132-I.

S. G. FRANTZ Co., Inc. . . . Engineers

P.O. Box 1138
Trenton 6, New Jersey, U.S.A.

Cable Address:
MAGSEP, Trentonnewjersey

ECONOMIC GEOLOGY ISSUES CONTAINING ARTICLES ON URANIUM

Individual numbers of Vols. 46, 50, 51, and 52 are $2.25 per number; for the current Vol. 53, $1.25 per number

VOL. 50, NO. 2. **URANIUM ISSUE** (12 articles on uranium)

VOL. 46, NO. 4. WILLIAM L. RUSSELL and S. A. SCHERBATSKOY: **The Use of Sensitive Gamma Ray Detectors in Prospecting**

VOL. 51, NO. 1. ROGER Y. ANDERSON and EDWIN B. KURTZ, JR.: **A Method for the Determination of Alpha-Radioactivity in Plants as a Tool for Uranium Prospecting.**

VOL. 51, NO. 2. PAUL B. BARTON, JR.: **Fixation of Uranium in the Oxidized Base Metal Ores of the Goodsprings District, Clark Co., Nevada.**

VOL. 51, NO. 3. GEORGE W. WALKER and FRANK W. OSTERWALD: **Uraniferous Magnetite-Hematite Deposit at the Prince Mine, Lincoln County, New Mexico.**

VOL. 51, NO. 4. J. RADE: **Notes on the Geotectonics and Uranium Mineralization in the Northern Part of the Northern Territory, Australia.**

GEORGE E. BOCRAFT: **Uranium Deposits of the Northern Part of the Boulder Batholith, Montana.**

VOL. 51, NO. 6. JOHN W. GRUNER: **Concentration of Uranium in Sediments by Multiple Migration-Accretion.**

R. S. MATHESON and R. A. SEARL: **Mary Kathleen Uranium Deposit, Mount Isa-Cloncurry District, Queensland, Australia.**

VOL. 51, NO. 7. EUGENE B. GROSS: **Mineralogy and Paragenesis of the Uranium Ore, Mi Vida Mine, San Juan County, Utah.**

VOL. 51, NO. 8. PAUL K. SIMS: **Paragenesis and Structure of Pitchblende-bearing Veins, Central City District, Gilpin County, Colorado.**

VOL. 52, NO. 1. ROBERT G. COLEMAN: **Mineralogical Evidence on the Temperature of Formation of the Colorado Plateau Uranium Deposits.**

TOMMY L. FINNELL: **Structural Control of Uranium Ore at the Monument No. 2 Mine, Apache County, Arizona.**

H. D. WRIGHT and D. O. EMERSON: **Distribution of Secondary Uranium Minerals in the W. Wilson Deposit, Boulder Batholith, Montana.**

D. W. BISHOP: **Notes on the Geotectonics and Uranium Mineralization in the Northern Part of the Northern Territory, Australia (Discussions).**

VOL. 52, NO. 2. H. D. WRIGHT and W. P. SHULPOF: **Mineralogy of the Lone Eagle Uranium-Bearing Mine in the Boulder Batholith, Montana.**

L. J. LAWRENCE: **Davidites from the Mt. Isa-Cloncurry District, Queensland.**

GEORGE W. BAIN: **Discussion of Urano-Organic Ores (Discussion).**

VOL. 52, NO. 3. FRANK C. ARMSTRONG: **Eastern and Central Montana as a Possible Source Area of Uranium.**

J. RADE: **Shearing Along Anticlines as an Important Structural Feature in Uranium Mineralization in the Northern Part of the Northern Territory of Australia.**

P. RAMDOHR: **Uraniferous Magnetite-Hematite Deposit at the Prince Mine, Lincoln County, N. M. (Discussion).**

VOL. 52, NO. 6. R. C. VICKERS: **Alteration of Sandstone as a Guide to Uranium Deposits and Their Origin, Northern Black Hills, South Dakota.**

CHARLES F. DAVIDSON: **On the Occurrence of Uranium in Ancient Conglomerates.**

VOL. 52, NO. 7. E. H. GOLDSTEIN: **Geology of the Dakota Formation Uraninite Deposit near Morrison, Colorado.**

VOL. 52, NO. 8. DONALD TOWSE: **Uranium Deposits in Western North Dakota and Eastern Montana.**

VOL. 53, NO. 2. H. D. HOLLAND, G. G. WITTER, JR., W. B. HEAD, III, and R. W. PETTI: **The Use of Leachable Uranium in Geochemical Prospecting on the Colorado Plateau. II The Distribution of Leachable Uranium in Surface Samples in the Vicinity of Ore Bodies.**

VOL. 53, NO. 3. A. VOLBORTH: **Identification Tables for Uranium and Thorium Minerals.**

J. J. BRUMMER: **Supergene Copper-Uranium Deposits in Northern Nova Scotia.**

VOL. 53, NO. 4. J. D. BATEMAN: **Uranium-Bearing Auriferous Reefs at Jacobina, Brazil.**

G. A. SCHNELLMANN: **On the Occurrence of Uranium in Ancient Conglomerates.**

C. J. SULLIVAN: **Ore Genesis—The Source Bed Concept.**

VOL. 53, NO. 5. LEO J. MILLER: **The Chemical Environment of Pitchblende.**

M. L. JENSEN: **Sulfur Isotopes and the Origin of Sandstone-Type Uranium Deposits.**

PAUL RAMDOHR: **On the Occurrence of Uranium in Ancient Conglomerates.**

J. A. S. ADAMS and RICHARD PLILER: **On the Occurrence of Uranium in Ancient Conglomerates.**

VOL. 53, NO. 6. CHARLES G. EVENSEN and IRVING B. GRAY: **Evaluation of Uranium Ore Guides, Monument Valley, Arizona and Utah.**

Order from: **ECONOMIC GEOLOGY PUBLISHING COMPANY**

105 Natural Resources Bldg., Urbana, Illinois

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

BULLETIN GÉODÉSIQUE

BEING

THE JOURNAL OF

THE INTERNATIONAL ASSOCIATION of GEODESY

★ ★ ★

The scientific articles appearing in this quarterly journal are prepared by the foremost geodesists and geophysicists in the world and deal with the following subjects: Mathematical geodesy (instruments, observations, calculation and adjustment of triangulation); astronomical determination of geographic positions; dynamic geodesy (gravimetry, figure of the Earth, earth tides, isostasy, etc.); leveling. It also contains a section of book notices.

Quarterly *1 volume per year $6.00 (£2.0.0) per volume*

Published by

PERGAMON PRESS

NEW YORK LONDON PARIS LOS ANGELES

122 East 55th Street, New York 22, N.Y. 4 & 5, Fitzroy Square, London W.1.

d. m. organist

PETROGRAPHIC LABORATORY

BOX 176 • NEWARK, DELAWARE

THIN SECTIONS OF

ROCKS, MINERALS, ORES, CERAMICS

PREPARED ROCK SECTIONS FOR STUDENT USE

GRAIN COUNTS • PETROGRAPHIC ANALYSIS

ANNOTATED BIBLIOGRAPHIES OF ECONOMIC GEOLOGY

Available—Vols. I–XXIX, No. 1 (1928–1956).

Vol. XXX (1957) current volume for 1958.

Price $5.00 per volume anywhere in the world thru Volume 27.
Effective Volume 28—price change to $6 per volume.

General Index, Vols. I–XXV, in preparation.

Order now from

ECONOMIC GEOLOGY PUBLISHING COMPANY

105 Natural Resources Building Urbana, Illinois

ECONOMIC GEOLOGY JOURNAL INDEX to Vols. XXXI–XL (1936–1945)—published September, 1947
Price $2.00

Also available Index to Vols. I–XX (1906–1926) —$3.00
Index to Vols. XXI–XXX (1927–1935)— 2.00
Index to Vols. XXXI–XL (1936–1945)— 2.00
Index to Vols. XLI–L (1946–1955) — 3.00

ECONOMIC GEOLOGY PUBLISHING COMPANY

105 Natural Resources Building Urbana, Illinois

FOR SALE

BACK VOLUMES OF ECONOMIC GEOLOGY

From Stock:

Complete Volumes: 3, 6, 7, 8, 9, 10, 11, 15, 22, 25 @ $15 per volume

Complete Volumes: 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 @ $12 per volume

Incomplete Volumes but from which certain issues are still available (some of them almost complete):
1, 2, 4, 5, 12, 13, 14, 16, 17, 18, 19, 21, 23, 24 @ $2.25 per issue

Also shelf worn copies of scattered numbers thruout the series @ 75¢ per copy

Inquire:

Economic Geology Publishing Company
105 Natural Resources Building
Urbana, Illinois

Special Price—

A. A. P. G. COMPREHENSIVE INDEXES, 1917—1955

Encompass all A.A.P.G.'s Bulletins and special publications for a 38-year period.
A valuable addition to the geologist's library. Cloth bound.

BOTH INDEXES	member price, $5.00; others, $7.00		
SINGLY	1917–45, one volume	3.00	4.00
	1946–55, one volume	3.00	4.00

ORDER FROM

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Box 979, Tulsa 1, Oklahoma, U. S. A.

ROCK THIN SECTIONS

MOUNTED ORE SECTIONS

Fred Roberts » » »

PETROGRAPHIC SECTION SERVICE

2636½ W. MAIN ST., ALHAMBRA, CALIFORNIA

SWAN ENGRAVING COMPANY

PHOTO ENGRAVERS COMMERCIAL ARTISTS

BRIDGEPORT, CONN. NEW HAVEN, CONN

POUGHKEEPSIE, N.Y.

Geophysics for Economic Geologists

GEOPHYSICAL CASE HISTORIES, VOLUME I (1948)	$7.00
GEOPHYSICAL CASE HISTORIES, VOLUME II (1956)	$7.00
CUMULATIVE INDEX, 1931–1953 (All publications)	$4.00
GEOPHYSICS (Quarterly)	Per year $10.00

Detailed list of publications on request

Send Order with Remittance to

SOCIETY OF EXPLORATION GEOPHYSICISTS
Box 1536 Tulsa 1, Oklahoma

PROBLEMS OF PETROLEUM GEOLOGY

Sidney Powers Memorial Volume

A Sequel to *Structure of Typical American Oil Fields*

A compilation of 43 papers prepared for this volume by 47 authors

1,073 pp., 200 illus. Cloth. Price, postpaid: to members, $4.00; to non-members, $5.00. Usual discounts to educational institutions.

The American Association of Petroleum Geologists
Box 979 . . . Tulsa 1, Oklahoma

A COMPLETE PRINTING SERVICE

GOOD PRINTING does not just happen; it is the result of careful planning. The knowledge of our craftsmen, who for many years have been handling details of composition, proofreading, presswork and binding, is at your disposal. For seventy-five years we have been printers of scientific and technical journals, books, theses, dissertations and works in foreign languages. Consult us about your next printing job.

• PRINTERS OF • ECONOMIC GEOLOGY

LANCASTER PRESS, Inc.

PRINTERS • BINDERS • ELECTROTYPERS

ESTABLISHED 1877 LANCASTER, PA.

Announcing

SPECIAL STUDENT SUBSCRIPTION RATES

ECONOMIC GEOLOGY

and the Bulletin of the Society of Economic Geologists:

An international journal devoted to the field of Economic Geology

Edited by ALAN M. BATEMAN

Business Editor, MORRIS M. LEIGHTON

8 issues per year

Regular subscription rate, $6.50, student rate, $4.00

(Canadian postage, 30¢)

Students registered in geology courses in the United States and Canada may send for application blank to: **Economic Geology Publishing Company, 105 Natural Resources Building, Urbana, Illinois.**